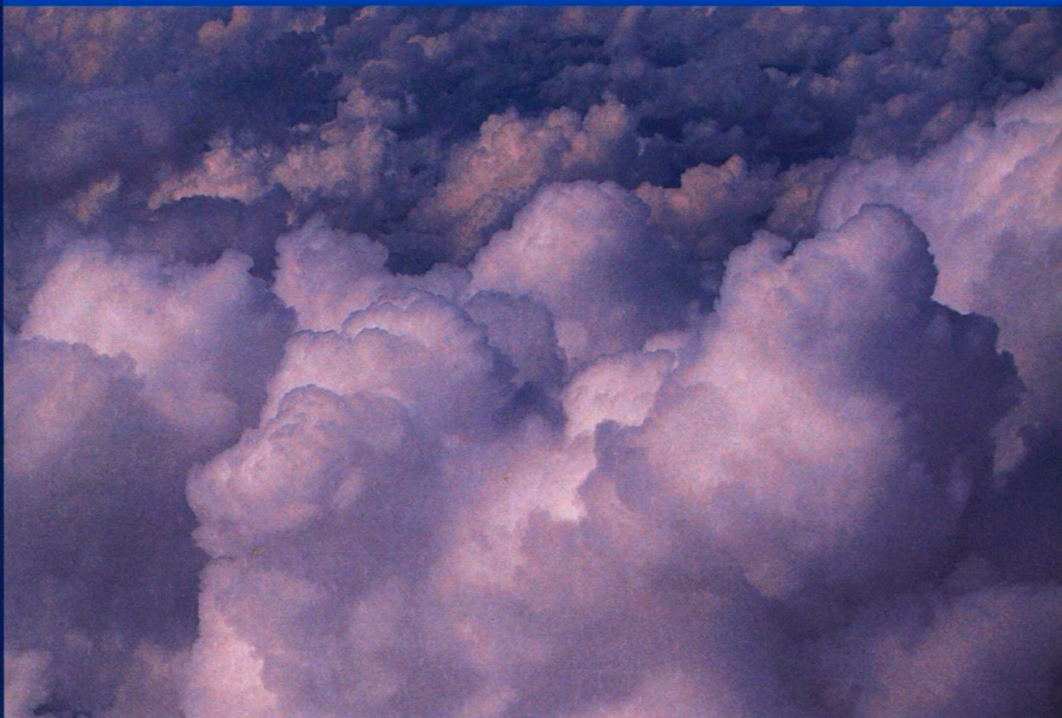
ACTA UNIVERSITATIS SZEGEDIENSIS

PARS CLIMATOLOGICA ET CHOROLOGICA
SCIENTIARUM NATURALIUM

Curat: János Unger

ACTA CLIMATOLOGICA ET CHOROLOGICA

TOMUS XLVI.



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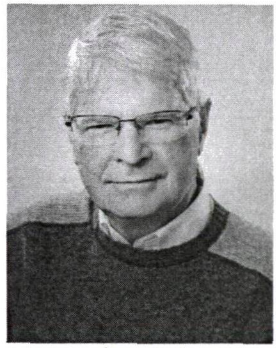
PREFACE

The present volume of Acta Climatologica et Chorologica Universitatis Szegediensis published by the Department of Climatology and Landscape Ecology, University of Szeged, is released on the occasion that in 2012 the department celebrates the 60th anniversary of its foundation. Since 60 years is a substantial period, the occasion deserves a little reminiscence: a brief review of the preludes of the foundation, the history of the following decades and in a bit more detail the educational and research work of the recent past and present. The first part of this volume contains this historical overview.

On the other hand this volume also serves as a tribute to the work of our colleague, Dr. László Makra, who also celebrates his 60th birthday this year. It summarizes his various publications, which cover a wide spectrum from meteorological and climatological studies published in high-impact journals through books about his expeditions to China and other exotic lands to writings in different science magazines. He has been teaching and carrying out research in our department since 1976 so if his student years are included he has had close ties with the department for over 40 years. His successful work is reflected by the long list of his publications, which is included in the second part of this volume. We wish him perseverance and similar success in his future endeavors.



Associate Professor
László Makra

The rest of the volume contains papers reflecting the latest research at the department as traditionally our journal provides publishing opportunities to our young and talented colleagues.

November 2012

János Unger
editor-in-chief, Acta Climatologica et Chorologica
head of department, Department of Climatology and Landscape Ecology

ACTA CLIMATOLOGICA ET CHOROLOGICA
Universitatis Szegediensis, Tomus 46, 2012, 7-14

THE DEPARTMENT OF CLIMATOLOGY AND LANDSCAPE ECOLOGY OF THE UNIVERSITY OF SZEGED IS 60 YEARS OLD – FROM THE BEGINNING TO PRESENT

J UNGER, I BÁRÁNY-KEVEI, T GÁL, Á GULYÁS, G KOPPÁNY, L MAKRA, Z SÜMEGHY and E TANÁCS

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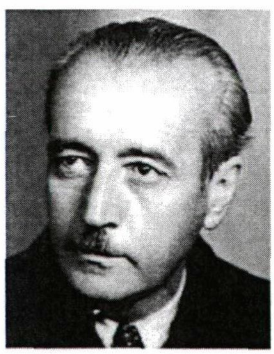
1. PRELUDE

After the turbulent years following World War I, in 1921 the geographers arriving to Szeged from the university in Cluj (Kolozsvár), which had come under Romanian rule, were temporarily placed in the building at No. 13 Dugonics Square. In the same year, the field of archaeology became independent and the Geographical and Historical Institute was founded with *Sándor Márki* in the lead. In 1923 *Károly Kogutowicz* was entrusted with the management of the (by then independent) Geographical Institute that he headed until 1944.

Sándor Márki (1853 – 1925), Head of the Institute between 1921 and 1923

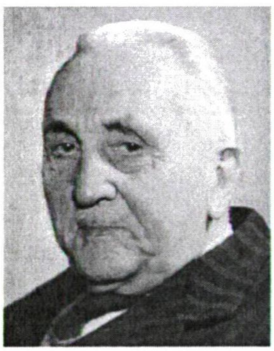


Károly Kogutowicz (1886 – 1948), Head of the Institute between 1923 and 1944

Károly Kogutowicz made considerable effort to enrich the material assets of his institution. As Head of the Institute and professor, he taught general and comparative geography; however besides his organisational activity he had little time for teaching therefore most of that task was undertaken by his colleagues (especially *Gábor Schilling*). In the years 1929-1930 he also held the position of Dean while in 1941-42 he became the Rector of the University of Szeged. His school atlas was widely used in geographical education even in the 1940's. He was a member of several scientific societies, among them the Hungarian Meteorological Society. He engaged in extensive public activity. He also extensively studied the issue of agriculture and exploitation possibilities of the Sand Ridge region west of Szeged. He created a model farm in Újszeged and landholders arriving for advice were daily guests at the institute. His most important works are various thematic maps and his two-volume book titled "Dunántúl és Kisalföld" (Transdanubia and the Little Plains).

Gábor Schilling (1887 – 1957), Professor of the Institute between 1921 and 1938

In 1925 the institution was given the new official name of Institute of Geography, Meteorological and Seismographic Observatory. The relatively new building of the Hungarian Central Railway Clearing Agency (finished in 1912) had already been offered to the future University of Szeged earlier but it only came to be effectively owned by the university in 1925, after the railway agency ceased to exist. The Geographical Institute was at first placed on the ground floor of the building, and then in 1930 it moved upstairs to the 3rd, 4th and 5th floors.



Gyula Prinz (1882 – 1973), Head of the Institute between 1945 and 1957

In 1940, the University of Szeged split in two: one part returned to Cluj (Kolozsvár), the other part became the Horthy Miklós University. In October 1944, as a result of war events, the university was evacuated and directed to Sopron, but some of the teachers went to Budapest, and the building became a Soviet military hospital. With the valuable instruments that had been wrapped in boxes and thus saved (although partly damaged) the work could begin again in the institute in the end of 1945, this time as part of the University of Szeged (from 1962 called József Attila University). Temporarily *Aurél Littke*, a retired professor of the Teacher's College assumed the leadership of the Institute of Geography. On 4 August 1945 *Gyula Prinz* was appointed Head of the Institute, who was also elected Dean of the Faculty of Arts for the academic year 1948/49. One of his young colleagues, *Richárd Wagner* habilitated in the summer of 1946 in the field of meteorology.

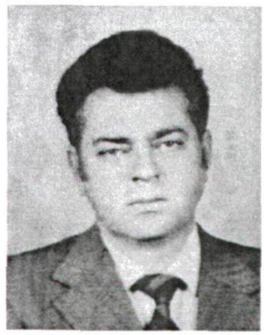
2. THE ESTABLISHMENT OF THE DEPARTMENT AND THE FIRST 40 YEARS

In 1952 the Institute of Geography was split in two; the No. 1 Institute of Geography was established under the leadership of *Gyula Prinz* while *Richárd Wagner* became head of the No. 2 Institute of Geography (from 1953 Institute of Climatology, from 1964 Department of Climatology). In the latter meteorological and climatological research has started and thus a university meteorological station could be established on the 5th floor. In 1959 the first volume of the Acta Climatologica Universitatis Szegediensis (from 2001 called Acta Climatologica et Chorologica) was published. This journal reflects the earlier and current scientific activity of the department.

Both the Institute of Geography and the Department of Climatology were in contact with the Hungarian meteorologists from the very beginning. Within the frames of this cooperation *Alfréd Hille* university lecturer taught meteorology at the University of Szeged from 1930, while from 1965 honorary professor *Béla Béll* held lectures. Alfréd Hille was one of the pioneers of aviation meteorology in our country, whereas Béla Béll was a prominent representative of high-atmosphere research (aerology) besides *György Marczell* (after whom the department's lecture hall was named).


Richárd Wagner (1905 – 1972), Head of Department between 1952 and 1972

When Richárd Wagner died in 1972, his successor was *György Péczely*. Under his leadership the department's research activities focused on synoptic and statistical climatology and additionally, an urban climate station network was established in Szeged, which operated for 3 years. Professor Péczely's work means an important milestone in the life of the department. In his time the educational and research work of the department was completely revamped. New subjects were introduced in the field of meteorology and climatology, and their teaching was mostly based on György Péczely's own notes and textbooks. Besides the scientific background of Professor Péczely his personality also contributed to a large number of students applying for faculty research work, the results of which were presented at the National Student Research Conferences. In 1981, the 15th such National Conference was held in Szeged and due to the large number of local applicants (13 people) a separate Climatology section had to be opened, in which only the students of the Department of Climatology, University of Szeged presented their work.


György Péczely (1929 – 1984), Head of Department between 1973 and 1984

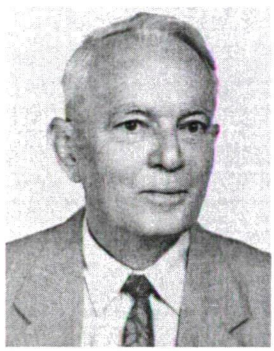
In 1983 the Department of Mineralogy, Geochemistry and Petrology together with the Department of Geology and Paleontology established the Geology Division, while the Departments of Physical Geography, Social Geography and Climatology formed the Geography Division. In the academic year 1986/87 the two merged and thus formed the Geography and Geology Division, whose first leader was Professor *Gyula Grasselly*.

On 3 March 1984 Professor György Péczely deceased. *János Juhász* was appointed as deputy then following his death in the autumn of the same year *László Jakucs* managed the department.

From the summer of 1986, until his retirement in 1995, *György Koppány* was the Head of Department of Climatology. Under his leadership new research directions were introduced such as historical climatology, the study of stratospheric ozone, and drought forecasting. Urban climate research also started at that time.

János Juhász (1921 – 1984), temporary Head of Department in 1984

László Jakucs (1926 – 2001), temporary Head of Department in between 1984 and 1986



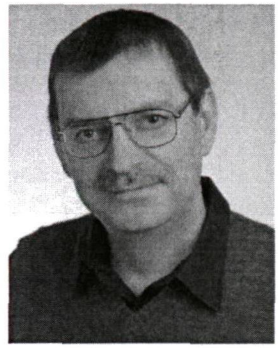
György Koppány (1932 –), Head of Department between 1986 and 1995

3. THE DEPARTMENT IN THE NEAR PAST AND TODAY

Between 1995 and 2006 *Ilona Bárány-Kevei* was the head of department, newly renamed to Department of Climatology and Landscape Ecology. She was the first female geographer in Hungary to become Doctor of the Hungarian Academy of Sciences (in 2003). Under her leadership, the department has expanded its research area to the field of landscape ecology. In 2007 *János Unger* took over the management of the department.

Today, the Department of Climatology and Landscape Ecology is responsible for several basic courses in the Earth Sciences, Geography, Environmental Science, Environmental Engineering and Physics BSc programmes. Meteorology, climatology, cartography and landscape ecology-themed subjects form a central part of the curriculum and are studied by a significant number of students. The department is involved in the Earth Science, Geographer and Environmental Science MSc programmes holding several applied courses and according to the plans it would play a role in the future Environmental Engineering MSc training as well.

Ilona Bárány-Kevei (1941 –), Head of Department between 1995 and 2006



János Unger (1958 –), Head of Department since 2007

The lecturers and the PhD students of the department conduct research in the fields of urban climate, air pollution and landscape ecology, which attract many students (dissertations, theses, student research). Related to these research topics, in the last 17 years fourteen people earned their PhD degrees, two habilitated and two persons earned the title Doctor of the Hungarian Academy of Sciences. Our support of the new generation and the involvement of the students in research are well demonstrated by the fact that our students won 16 prizes and special prizes at the National Student Conferences with studies related to ongoing projects. The department maintains research collaboration with a number of Hungarian and foreign research institutions of similar profile (e.g. Albert-Ludwigs Universität Freiburg, HAS Research Centre of Ecology, Institute of Ecology and Botany, Wageningen University and Research Centre, Corvinus University of Budapest, Eötvös Loránd University, Debrecen University, Hungarian Meteorological Service, University of Novi Sad, etc.).

Our urban climate research focuses on the climate-modifying effects of the artificial urban environment, particularly excess temperature and its governing factors. We are looking for the relationship between city districts classified in local climate zones and their thermal characteristics. Furthermore human comfort analyses are carried out in different urban micro-environments, both using measurements and modeling. In the future, these thermal comfort condition analyses are planned to be extended in the form of parallel measurements and human monitoring based on extended instrumentation in several areas of the city, which are suitable for recreation. We would also simulate the changes of comfort conditions according to different climate change scenarios.

Our latest research analyses in detail the climatic impact of urban woody vegetation e.g. by working out methods, which make it possible to model the radiation-modifying effect of trees. These studies are partly connected to landscape ecological research since they also aim to analyze several other aspects of the woody vegetation and a wide spectrum of their ecological services. Another branch of our urban climatological research deals with the meteorological and climatological effects of complex urban surface geometry. In the course of these investigations, a 3D building database of the city of Szeged was created, which contains most of the buildings of the inner areas along with their height data. This database is currently further extended within the frames of a project by the automated measurement of the woody vegetation. Related to this branch of research a number of software processes and models have been created, such as a method for calculating the sky view factor, which has considerable impact on the urban radiation budget or a simple method for the delineation of urban ventilation paths. This research direction focuses in the short term on utilizing the developed methods in urban planning but at the same time our long-term goal is to appropriately describe urban surface geometry and its effects on urban atmosphere so that urban areas and their processes can be integrated into different meteorological and climatological numerical simulation models.

The complex landscape ecological research (including climate, topography, soil, wildlife and landscape history-related topics) conducted at the department is, in part due to the traditions, still mostly related to karstecology. Besides the analysis of karst morphological processes and the investigation of the water quality of karstic lakes, we also study stand dynamics in karstic forests. Our long-term study site is the Haragistya-Lófej forest reserve in Aggtelek Karst, where the forest stand characteristics, spatial and temporal patterns are analyzed in terms of management history and site characteristics. Temporal changes of the forest cover in Hungarian karst areas are also studied using EO data (aerial photographs, satellite images) and object-based image analysis. Related to the above we investigate the ecosystem services (timber production, C-sequestration, etc.) of the natural and managed forests as well as the related land use conflicts in different types of areas. A new research has recently started in the floodplain area of the river Maros, which aims to evaluate the local forest ecosystem services in order to compare different-intensity management alternatives of the riparian forests in the interests of identifying the most appropriate floodplain land use.

In the course of our air pollution-related research, we identify the long-term transport systems modifying the local PM_{10} and ragweed pollen concentrations in the frames of the meteorological aspects of air pollutants for various European cities using the HYSPLIT dispersion model. In the future, we work out new techniques for the prediction of ragweed pollen characteristics, which could be recommended for use by the media. We would also try out some new methods, so far unused for predicting ragweed pollen concentration and compare the effectiveness of these methods. We analyze the relationship of respiratory diseases with the meteorological elements, as well as chemical and biological air pollutants. We furthermore study the relationship between allergic asthma emergencies, allergic rhinitis and the main biological and chemical air pollutants with particular regard to extreme patient numbers.

We study the climate sensitivity of different taxa in the context of global warming by introducing new statistical procedures and new climate change imperatives. We examine the effect of land use changes on the current pollen concentrations and separate the effect of the present meteorological elements and past climatic parameters on the different taxa using a new statistical method and we determine the actual weight of these factors. We analyze the role of socio-demographic and environmental factors in the development of allergic rhinitis and asthma. We study the interdiurnal variability of the pollens of the selected taxa in the context of the meteorological elements. We examine the relationship between the phenological and quantitative characteristics of the pollination and the extreme values of meteorological elements; furthermore we are looking for a relationship between the rank of importance of the pollen characteristics and the rank of importance of the annual values of meteorological variables. We also analyze how the values of meteorological elements relate to extreme Ambrosia pollen loads, and the extreme pollen load considering all the other taxa, with the exception of the Ambrosia pollen.

The current cartographic research at the department is multidirectional. The objective of our thematic cartographic research is the investigation of the theoretical and practical background and regularities of editing digital maps of a variety of natural and social subjects, in particular the applicability of GIS-supported cartographic methods in different areas (e.g. research, risk assessment, decision-making). Our research of cognitive and mental maps and mapping aims a better understanding of the subjective aspects that the real maps do not contain, yet they are an important source of information on the map-makers themselves (their views of the world, values, the love of their homes, their identification with it, prejudices, misbelieves and desires). Recalling and analyzing such hidden aspects of our spatial world view can facilitate the solution in many issues (e.g. urban spatial planning or research of the relationship to our environment or on our decisions). Involving students, we investigate mental maps made about different areas according to the gender, age, place of origin, ethnic and cultural affiliation, educational background and social status of the maps' creators.

Our cartography historical research has both Hungarian and international aspects. The largest and longest-term project is the detailed analysis of Dutch-made maps and atlases of a half-century (approximately between 1680 and 1730) period. At this time the Dutch map and atlas publishers rarely or not at all dated their works. Thus, the history of map and atlas publication in this era is quite vague on many points. In order to clarify it we have developed a complex method, which is based on many pillars; its application is still in progress, but it has already produced many results and inspired attention.

In our department a meteorological station of the Hungarian Meteorological Service (OMSZ) has been operating since 1999 (supplemented by the measurements of the OMSZ Szeged Regional Centre). The data can be followed through an online visualization system since 2009. The measurement data of the two stations (including the visual perceptions of the outlying station, and the wind profiles) are available for both education and research purposes. We work in close cooperation with the staff of the Regional Centre, so our students studying in the Earth Science BSc programme have an opportunity to get to know the meteorological station and the measurements carried out there as well.

The instrumentation of the department, which can also be used for the students' work consists of a variety of traditional analog instruments, digital temperature, humidity and wind data loggers, and two mobile micro-climate measurement units. The lectures are held in a 48-seat modern and well-equipped classroom at the department, or in the 200-seat auditorium and two computer labs (where a total of 70 advanced workstations are available) of the division.

The current staff of our department are the following: Dr János Unger head of department - associate professor, Dr Tamás Gál deputy head of department - assistant professor, Dr Ágnes Gulyás deputy head of department - assistant professor, Dr. Ilona Bárány-Kevei professor emerita, Dr László Makra associate professor, Dr Zoltán Sümeghy assistant professor, Dr Eszter Tanács assistant professor, Dr Noémi Kántor research assistant, Éva Kosztolányi administrative secretary. The PhD students of our department in 2012 are the following: Zoltán Csépe, Lilla Égerházi, Márton Kiss, Attila Kovács, Mária Kovács, Enikő Lelovics.

The current staff and PhD students of the department. Standing in the back row (from left to right): Z Sümeghy, Z Csépe, É Kosztolányi, J Unger, N Kántor, M Kiss and L Makra; Sitting in the front row (from left to right): I Bárány-Kevei, Á Gulyás, L Égerházi, A Kovács, E Tanács, E Lelovics and T Gál

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1978

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1980

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ASSOCIATION OF SOCIODEMOGRAPHIC AND ENVIRONMENTAL FACTORS WITH ALLERGIC RHINITIS AND ASTHMA

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Summary: Asthma and allergic rhinitis can play an important role in the quality of life, and its components are not clearly understood. The aim of the study is to analyse the role of socio-demographic and environmental factors in developing allergic asthma and rhinitis. The data set of the study is a questionnaire-based survey, with altogether 3666 interviewees. Altogether 26 socio-demographic and environmental variables are considered in the statistical analysis. Furthermore, seven resultant variables inducing allergic reactions were considered. They are as follows: dust, pollen, food, skin, pet, medicine and insect byte. For this, canonical correlation analysis (CCA) and a factor analysis with special transformation was performed in order to find out the strength and direction of the socio-demographic and environmental factors examined in forming certain allergic diseases.

Key words: asthma, allergic rhinitis, questionnaire-based survey, socio-demographic and environmental factors, canonical correlation analysis, factor analysis and special transformation

1. INTRODUCTION

Air pollution is a permanently increasing environmental hazard. During the last three decades there has been a persistent rise in both allergic diseases and allergic sensitisation (Batlles-Garrido et al. 2010). Furthermore, based on historical records, the prevalence of allergic rhinitis (AR) and allergic asthma have significantly increased over the past two centuries. Although the reasons for this increase are not fully clarified, epidemiologic data suggest that certain pollutants produced from the burning of fossil fuels may have played an important role in the changes of prevalence (Peterson and Saxon 1996). This increase may be partly explained by changes in environmental factors. Urbanization, increasing automobile traffic, high levels of vehicle emissions, as well as the changing environment, lifestyle and living conditions are associated to the increasing frequency of allergic diseases (D'Amato et al. 2005, Batlles-Garrido et al. 2010).

Weather conditions can also influence both biological and chemical air pollutants. There are evidences on the effect of air pollution upon allergens, increasing exposure to the latter, their concentration and/or biological allergenic activity (Bartra et al. 2007). Furthermore, simultaneous exposure to more than one allergen might modify the effect of individual allergens (Custovic et al. 2003).

Allergies give rise to the fifth leading group of chronic diseases (Singh et al. 2010) and allergic rhinitis is considered to be the most frequent allergic disorder becoming a major public health problem in developed countries (Todo-Bom et al. 2007, Navarro et al.

2009). Allergic rhinitis represents a significant health problem because of the high variety of symptoms and its impact on general well-being and quality of life (QoL) among patients consulting for this condition (Canonica et al. 2008).

Air pollution in Hungary belongs to the highest in Europe concerning both ambient PM_{10} concentrations (Bozó et al. 2003) and pollen load (Makra et al. 2005). The concentration of *Ambrosia* pollen in Central Europe including Hungary is around one order of magnitude higher than in the remaining parts of the continent. In Southern Hungary, *Ambrosia* produces 44.1% of the total pollen production, indicating that ragweed is the most important aero-allergen taxon in Hungary (Juhász and Juhász 1997). In Szeged, 83.7% of the patients were sensitive to *Ambrosia* in 1998-1999 (Kadocsa and Juhász 2000). About 30% of the Hungarian population has some type of allergy, 65% of them have pollen-sensitivity, and at least 60% of this pollen-sensitivity is caused by *Ambrosia* (Járai-Komlódi 1998). The number of patients with registered allergic illnesses has doubled and the number of cases of allergic asthma has become four times higher in Southern Hungary by the late 1990s over the last 40 years (Makra et al. 2005).

Economic losses due to the crop loss through the expanded vegetating of ragweed, expenses of protection, the number of days on sick-leave, expenses of medicines, medications and hospitalizations, other direct and indirect effects (drop-out of labour from production, losses from tourism and natural protection, seed-corn contaminated by ragweed seeds) produce further losses. Total annual losses due to ragweed and ragweed pollen in Hungary can reach 400-800 million € (Mányoki et al. 2011).

Allergic rhinitis (AR) is a common inflammatory condition of the nasal mucosa, characterised by nasal pruritus, sneezing, rhinorrhoea, and nasal congestion. AR is mediated by an IgE-associated response to ubiquitous indoor and/or outdoor environmental allergens (Dullaers et al. 2012).

Asthma is defined as a chronic inflammatory disorder, where the chronic inflammation is associated with airway hyper-responsiveness that leads to recurrent episodes of wheezing, breathlessness, chest tightness and coughing particularly at night or in the early morning (Global Strategy for Asthma Management and Prevention 2010). Asthma is caused by environmental and genetic factors (Martinez 2007), which influence the severity of asthma. The interaction of these factors is complex and not fully understood (Miller and Ho 2008).

Many patients with asthma, particularly those with allergic asthma, also have AR. The mucosa of the upper and lower airways is continuous, and the type of inflammation in AR and asthma is very similar, involving T helper type 2 cells, mast cells, and eosinophils (Jeffery and Haahtela 2006). Both diseases have characteristic symptoms and are strongly influenced by environmental factors.

A number of characteristics were identified that can lead to an increased risk of pollutant-related respiratory diseases, including sex, age (i.e., children, adults and the elderly), pre-existing respiratory diseases and low socio-economic status (Sacks et al. 2011).

Differences can be observed in the prevalence of allergy and asthma for urban/rural scale, as well as for developed/developing country comparisons. In West Germany, the prevalence of sensitizations was slightly higher in urban than in rural areas (Krämer et al. 1999), furthermore, at the time of the German reunification in 1990, most allergic diseases were less prevalent in East than in West Germany (Krämer et al. 2010). Parallel to this, El-Sharif et al. (2003) detected lower rates for asthma and asthma symptoms on Palestinian school children aged 6-12 years compared to those in economically developed and industrialized countries. Recent studies of children suggest that factors encountered in a farm environment might protect against the development of allergy. Farmers' children are less frequently sensitized to "common" allergens (grass pollen, dog, cat, birch, mugwort) than the non-farmers' children (Remes et al. 2005, Norback et al. 2007). Farm environment reduces the occurrence of asthma, allergic diseases, and atopic sensitization in children, and also the occurrence of allergen-induced rhinitis (Leynaert et al. 2001, Remes et al. 2005, Waser et al. 2005). Furthermore, Koskela et al. (2003) suggests that animal husbandry may also decrease the risk of pet- and pollen-induced upper airway symptoms among female adults. A hypothesis of potential protective effects of exposure to pets during early childhood on the development of atopic disorders in children later in life is supported (Anyo et al. 2002, Holscher et al. 2002, Custovic et al. 2003). Among the single allergens, sensitization against pets or pollen, or against horse or cow, had the strongest association with asthma and hay fever (Remes et al. 2005).

Asthma and allergic rhinitis can play an important role in the quality of life, and its components are not clearly understood. Namely, the influence of socio-demographic and environmental factors on QoL in patients with AR has been so far little investigated (Laforest et al. 2005). The aim of the study is to analyse the role of socio-demographic and environmental factors in developing allergic asthma and rhinitis. For this, canonical correlation analysis (CCA) and a factor analysis with special transformation was performed in order to find out the strength and direction of the socio-demographic and environmental factors examined in forming certain allergic diseases.

2. MATERIALS AND METHODS

2.1. Materials

The data set of the study is a questionnaire-based survey, containing the data of altogether 3666 subjects. The questionnaire comprises 42 questions that can be classified in 11 topics, as follows: (1) individual parameters (gender, birth data and profession); (2) education; (3) diseases of the parents and siblings; (4) own diseases and diseases of own children; (5) breastfeeding; (6) own non-allergic diseases; (7) own allergic diseases; (8) alcohol; (9) smoking; (10) living conditions and (11) home interior. Furthermore additional information was also considered (symptoms denoting allergy, diagnosed allergy, and regular medication).

Altogether 26 socio-demographic and environmental variables are considered in the statistical analysis. Their possible role in developing asthma and allergic rhinitis are examined. These variables are as follows: breastfeeding (yes/no), high blood pressure, vascular diseases, heart disease, lung diseases, diabetes, obesity, cancer, alcohol (yes/no), smoking (yes/no), urban apartment living, live in apartment housing, family house living, concrete wall of the housing, brick wall of the housing, adobe walls of the housing, state of the housing walls (dry, wet), parquet flooring in the house, the flat floor carpet, the flat floor stone, the bedding material (feather, non-feather), dog, cat, chicken, pig and cattle. Furthermore, seven resultant variables inducing allergic reactions were considered. They are as follows: dust, pollen, food, skin, pet, medicine and insect byte.

The mean age of those who were interviewed was 30.8 years, the youngest person was 16, while the oldest 107. The sample examined was not random, since most of the interviewed people were students. Out of those 3666 people who were interviewed, 1598 people were male and 2060 female. 1860 people didn't have any kind of allergy, while 1798 people were sensitive to at least one allergen. The highest education level was nothing in the case of 10 people, primary school for 146 individuals secondary school for 1630, higher educational institution and university or part of it in the case of 689 and 1183 people, respectively. Out of all the interviewed individuals 1780 people were young (15 yr < age ≤ 24 yr) (787 males and 993 females), 1410 people wee adults (619 males and 791 females), furthermore 283 people were elderly (101 males and 182 females).

Data preparation, part of the calculations and graphic editing was performed with *EXCEL 2007* software. At the same time, factor analysis was carried out with *SPSS 16.0* software.

2.2. Methods

2.2.1. Pearson's chi-squared test

Pearson's chi-squared test (χ^2) examines a null hypothesis stating that the frequency distribution of certain events observed in a sample is consistent with a particular theoretical distribution. The events considered must be mutually exclusive and have total probability 1. Pearson's chi-squared goodness of fit test establishes whether or not an observed frequency distribution differs from a theoretical distribution (Bolla and Krámli 2005).

2.2.2. Canonical correlation analysis (CCA)

If we have a set of explaining variables $X = (x_1,\ldots x_p)^T$ and a set of target variables $Y = (y_1,\ldots,y_q)^T$, and there are correlations among the variables, then canonical correlation analysis will enable us to find linear combinations of the components of X and Y which have maximum correlation with each other.

Canonical correlation analysis (CCA) seeks vectors a and b so that the random variables $a^T X$ and $b^T X$ maximize the canonical correlation $\rho = corr[a^T X, \ b^T Y]$. The random variables $u = a^T X$ and $v = b^T Y$ represent the first pair of canonical variables. Then one seeks vectors maximizing the same correlation subject to the constraint that they are to be uncorrelated with the first pair of canonical variables; this gives the second pair of canonical variables. This procedure may be continued up to $m = \min \{p,q\}$ times.

Each canonical correlation can be tested for significance the following way. Saying that the ith canonical correlation is zero implies all further correlations are also zero. If we have n independent observations in a sample and $\hat{\rho}_i$ is the estimated canonical correlation, the test statistic is:

$$\chi^2 = -(n-1-(p+q+1)/2)\ln\prod_{j=i}^{m}(1-\rho_j^2) \tag{1}$$

which is asymptotically distributed as a chi-squared with $(p - i + 1)(q - i + 1)$ degrees of freedom for large n.

The visualization of the results of the canonical correlation ρ_i is usually through tables for the coefficients $a_i^T = (a_{i1},...,a_{ip})$ and $b_i^T = (b_{i1},...,b_{iq})$ of the two sets of variables for the pairs of canonical variables showing significant correlations between the original and canonical variables. In order to ensure an easier interpretation the canonical correlation analysis is performed with standardized explaining and target variables. The standardization of a random variable means a simple transformation resulting in a variable with zero expectation and unit variance.

Supposing that $q < p$ (which is a typical case) and supposing that every canonical correlation is significant, then the estimate $\hat{Y}$ of Y is

$$\mathrm{Y} = (\mathrm{B}^{-1}\mathrm{RA})\mathrm{X} \tag{2}$$

where the ith row of A and B is a_i^T and b_i^T respectively, and R is a diagonal matrix with ρ_i in its ith diagonal element (Johnson and Wichern 2007).

2.2.3. Factor analysis and special transformation

Factor analysis (FA) identifies linear relationships among subsets of examined variables, which helps to reduce the dimensionality of the initial database without any substantial loss of information. First, a factor analysis was applied to the initial dataset consisting of 26 explanatory variables in order to transform the original variables to fewer variables. These new variables called factors can be viewed as the main socio-demographic/environmental functions that potentially influence allergic sensitivity. The optimum number of retained factors is determined by the criterion of reaching a prespecified percentage of the total variance (Jolliffe 1993). This percentage value was set at 80% in our case. After performing a factor analysis, a special transformation of the retained factors was performed to discover to what degree the above-mentioned 26 explanatory variables affect the 7 resultant variables (7 type of allergy), and to give a rank of importance of their influence (Fischer and Roppert 1965, Jahn and Vahle 1968, Jolliffe 1993).

Thresholds of significance are obtained according to the following consideration. Introducing the null-hypothesis that a given factor loading (weight) is zero, i.e. this factor is not present in forming the resultant variable, the statistics

$$\mathrm{t} = \sqrt{\frac{\mathrm{r}^2(\mathrm{n}-2)}{1-\mathrm{r}^2}} \tag{3}$$

follows a Student t-distribution with $n-2$ degrees of freedom, where r is the value of the given factor loading and n is the number of data.

3. RESULTS

3.1. Pearson's χ^2-test

It was analysed whether the pairwise frequencies of non-sensitive individuals and those who are sensitive at least to one allergen differ significantly on the basis of the 26 explanatory variables. We found that those suffering from lung disease are substantially more sensitive to at least one allergen (99% probability level), while for those living in family house and breeding chicken or pig, the number of sensitive individuals is remarkably smaller (95% and 99% probability levels) (Table 1).

Table 1 Frequency of non-sensitive individuals and those being sensitive at least to one allergen according to the explanatory variables

Explanatory variables	Non-sensitive individuals	Those being sensitive To at least one allergen	Total
Breastfeeding (yes/no)	1704	1625	3329
High blood pressure	300	307	607
Vascular diseases	108	111	219
Heart disease	92	119	211
Lung disease	**38**	**134**	**172**
Diabetes	50	59	109
Obesity	268	282	550
Cancer	21	23	44
Alcohol (yes/no)	0.45	0.44	0.89
Smoking (yes/no)	0.42	0.46	0.88
Urban apartment living	1003	1070	2073
Live in apartment housing	436	487	923
Family house living	*1151*	*1035*	*2186*
Concrete wall of the housing	418	449	867
Brick wall of the housing	1297	1218	2515
Adobe walls of the housing	289	242	531
State of the housing walls (dry, wet)	1.08	1.11	2.19
Parquet flooring in the house	1286	1192	2478
The flat floor carpet	589	593	1182
The flat floor stone	469	418	887
The bedding material (feather, non-feather)	1.54	1.69	3.23
dog	962	891	1853
cat	660	646	1306
chicken	**294**	**220**	**514**
pig	**149**	**106**	**255**
cattle	24	37	61

Bold: significant at the 99% significance level; *Italic:* significant at the 95% significance level

The frequencies of those being sensitive to at least one allergen were determined for all 7 allergens. Thereafter, these frequencies were summarised for young individuals, adults and the elderly, according to sex. Then we analysed whether the pairwise frequencies for all three age categories and sex differed significantly. We received that for young individuals (15 yr < age ≤ 24 yr) the ratio of females suffering from any kind of allergy is remarkably higher compared to males (99% probability level); for adults (25 yr < age ≤ 54 yr) the ratio of sensitive individuals is also higher for females, but there is no significant difference (75% probability level); furthermore, for the elderly (age > 54 yr) females are also more sensitive to any allergen compared to males indicating a weakly significant association (90% probability level) (Table 2).

Table 2 Frequency of those being sensitive to at least one allergen for the individual categories

Resultant variables (allergens)	Males			Females			Total		
	[1]Young subjects	[2]Adults	[3]The elderly	[1]Young subjects	[2]Adults	[3]The elderly	[1]Young subjects	[2]Adults	[3]The elderly
Dust	7	7	4	8	13	4	7	12	4
Pollen	7	10	5	12	13	6	10	12	8
Food	6	6	0	14	8	4	9	9	6
Skin	6	5	1	11	7	6	8	7	5
Pet	6	8	3	9	9	6	8	11	4
Medicine	4	7	3	6	11	3	3	9	5
Insect bite	2	12	4	8	8	5	6	10	5

[1]: 15 yr < age ≤ 24 yr; [2]: 25 yr < age ≤ 54 yr; [3]: age > 54 yr

3.2. Canonical correlation analysis (CCA)

3.2.1. All sensitive individuals

When applying canonical correlation analysis, the period of breastfeeding was dropped out. Namely, due to preliminary examinations this variable does not explain anything about allergic diseases.

Three canonical variable pairs were found significant at 95% probability level. These are worth further consideration.

The importance and direction (sign) of the individual variables in forming the canonical variables can be measured by the coefficient of the actual variable. Further important information is the correlation between the original variables and the canonical variables belonging to them. These two characteristics definitely don't behave similarly, so they should be considered simultaneously. The most relevant results of these two variable pairs are as follows.

First canonical variable pair: The most remarkable explaining variables are the bedding material and lung disease in decreasing order of importance. Urban environment (urban apartment living) and partly the state of the housing walls are also important (Table 3). The coefficients are positive (Table 3) and since the coefficients of the first canonical variable of the resultant variables are also positive (Table 4), these explaining variables induce allergic symptoms, namely pollen-, dust- and pet allergy, in decreasing order of importance (Tables 3-4).

Second canonical variable pair: In the canonical variables of the resultant variables insect byte and pollen allergy are dominant, with different signs. Hence, there is a tendency that someone has one kind of allergy but misses the other (Table 4). The most relevant explaining variables are parquet flooring in the house (based on signs, pollen allergy tends to occur in apartments with parquet flooring), dog and vascular disease (they have an inverse and a proportional relationship with pollen-, and insect byte allergies, respectively), as well as alcohol (being in a proportional and an inverse association with pollen- and insect byte allergy, respectively) (Tables 3-4).

Table 3 Coefficients of explaining variables in the canonical variables and correlations between explaining variables and canonical variables (**bold**, ***bold italic*** and *italic* refer to correlations different from zero at 99.9, 99 and 95% significance levels)

Explanatory variables	Canonical variables 1		2		3	
	Coefficient	Correlation	Coefficient	Correlation	Coefficient	Correlation
Breastfeeding (yes/no)	0.0579	0.0314	0.1208	0.0315	0.2875	**0.2180**
High blood pressure	-0.0802	**-0.0626**	-0.0377	**0.1005**	0.2262	**0.1535**
Vascular diseases	0.0043	-0.0303	0.3716	**0.3206**	0.2319	**0.1198**
Heart disease	0.1764	**0.0970**	0.1038	**0.1371**	-0.3265	**-0.1751**
Lung disease	1.0192	**0.5885**	-0.0863	-0.0072	0.1983	**0.0938**
Diabetes	-0.0921	-0.0097	0.1955	**0.2090**	-0.2766	**-0.1377**
Obesity	0.0559	**0.0635**	0.2582	0.3176	-0.2032	**-0.1781**
Cancer	-0.0657	0.0166	0.2327	**0.1196**	-0.1864	*-0.0362*
Alcohol (yes/no)	0.0943	**0.1172**	-0.2648	**-0.3728**	0.1562	**0.2158**
Smoking (yes/no)	-0.1028	**-0.0787**	0.0618	*0.0377*	-0.0037	***0.0453***
Urban apartment living	0.2203	**0.3574**	0.1063	**-0.0865**	-0.3241	**-0.4152**
Live in apartment housing	0.0891	**0.2272**	-0.0253	**-0.1245**	0.0569	**-0.1311**
Family house living	0.0732	**-0.2755**	0.0854	**0.1758**	0.0206	**0.2476**
Concrete wall of the housing	-0.0591	**0.1661**	-0.0290	**-0.0817**	-0.0093	**-0.1411**
Brick wall of the housing	-0.0582	**-0.0714**	-0.0257	0.0141	0.0538	***-0.0459***
Adobe walls of the housing	-0.0799	**-0.1764**	-0.1302	***0.0534***	0.2912	**0.3320**
State of the housing walls (dry, wet)	0.2211	**0.1504**	0.2567	**0.2663**	-0.0136	*0.0364*
Parquet flooring in the house	-0.0438	-0.0113	-0.4359	**-0.5192**	-0.2991	**-0.3035**
The flat floor carpet	-0.0048	-0.0078	-0.1035	**0.1513**	-0.1244	0.0252
The flat floor stone	-0.0071	**-0.0738**	-0.0774	0.0201	-0.0554	0.0032
The bedding material (feather, non-feather)	0.5267	**0.7125**	0.0433	-0.0038	-0.0535	**-0.1281**
Dog	0.0121	**-0.2002**	0.3749	**0.4587**	-0.0599	**0.0708**
Cat	-0.0532	**-0.1816**	-0.2149	**-0.1325**	-0.4571	**-0.4541**
Chicken	-0.0758	**-0.2338**	-0.1856	**0.0582**	0.1215	**0.2011**
Pig	-0.1165	**-0.2159**	0.2690	**0.1898**	0.1175	**0.1667**
Cattle	0.1265	-0.0157	0.0580	**0.0898**	-0.1435	0.0322

Table 4 Coefficients of target variables in the canonical variables and correlations between target variables and canonical variables (**bold**, ***bold italic*** and *italic* refer to correlations different from zero at 99.9, 99 and 95% significance levels)

Resultant variables	Canonical variables 1		2		3	
	Coefficient	Correlation	Coefficient	Correlation	Coefficient	Correlation
Dust	0.4613	**0.7526**	-0.1547	**-0.2849**	0.2615	**0.1698**
Pollen	0.5405	**0.7551**	-0.4772	**-0.5480**	-0.4037	**-0.4038**
Food	-0.0091	**0.1568**	-0.1405	*-0.0361*	-0.6187	**-0.5759**
Skin	0.0822	**0.1786**	0.2540	**0.2639**	-0.4248	**-0.4930**
Pet	0.6324	**0.6677**	0.2940	**0.1016**	0.3576	**0.2169**
Medicine	0.2936	**0.2560**	0.3479	**0.3773**	0.1901	**0.1038**
Insect bite	0.0459	**0.1500**	0.6757	**0.6192**	-0.2034	**-0.2630**

Third canonical variable pair: The most remarkable resultant variables are food-, skin- and pollen allergy in decreasing order of importance and with the same sign. These kind of allergies are facilitated by cat, urban apartment living and parquet flooring in the house in decreasing order of importance, while adobe walls are of opposite effect (Tables 3-4).

3.2.2. Sensitive males

First canonical variable pair: The most important explanatory variables are lung disease and bedding material. Urban environment (urban apartment living) and partly the state of the housing walls are also relevant (Table 5). The coefficients are positive (Table 5) and since the coefficients of the first canonical variable of the resultant variables are also positive (Table 6), accordingly allergic symptoms (mainly pollen-, dust- and pet allergies) are induced by these variables (Tables 5-6).

Table 5 Correlations between explaining variables and canonical variables (**bold**, ***bold italic*** and *italic* refer to correlations different from zero at 99.9, 99 and 95% significance levels)

Explaining variables	Canonical variable 1		Canonical variable 2	
	Males	Females	Males	Females
Breastfeeding (yes/no)	**0.0770**	-0.0105	-0.2083	**0.2012**
High blood pressure	-0.0361	**0.1969**	0.0188	**-0.1352**
Vascular diseases	-0.0240	**0.7029**	**0.2835**	***-0.0505***
Heart disease	**0.0949**	**0.0791**	**0.1181**	0.0252
Lung disease	**0.6902**	0.0295	*0.0417*	**0.4488**
Diabetes	-0.0095	**0.0901**	**0.2846**	0.0346
Obesity	**0.0977**	**0.1201**	***0.5251***	**-0.1647**
Cancer	*0.0447*	0.0346	**0.0629**	*0.0390*
Alcohol (yes/no)	**-0.1975**	0.0290	***0.0513***	**-0.1228**
Smoking (yes/no)	**0.1612**	-0.0116	**-0.1577**	**0.1752**
Urban apartment living	**0.1997**	**0.7004**	**-0.1058**	-0.0211
Live in apartment housing	**0.0749**	**0.3449**	***0.0554***	0.0218
Family house living	**-0.0807**	**-0.4901**	-0.0110	0.0282
Concrete wall of the housing	-0.0215	**0.2354**	**0.1592**	***0.0466***
Brick wall of the housing	**0.0659**	**-0.1146**	**-0.1070**	**-0.0595**
Adobe walls of the housing	**-0.1396**	**-0.1654**	**-0.1010**	0.0357
State of the housing walls (dry, wet)	**0.1381**	-0.0202	**0.3013**	**0.2690**
Parquet flooring in the house	**0.1802**	-0.0041	**-0.5825**	**-0.3757**
The flat floor carpet	**-0.1662**	-0.0367	**0.0841**	**0.6623**
The flat floor stone	**-0.1649**	**-0.0736**	-0.0185	**-0.2101**
The bedding material (feather, non-feather)	**0.4959**	0.0047	-0.0340	**0.0938**
Dog	**-0.2536**	**-0.3153**	**0.2071**	***0.0490***
Cat	0.0056	**-0.1505**	**0.1618**	**0.2874**
Chicken	**-0.2528**	**-0.1379**	**0.0856**	*0.0408*
Pig	**-0.1944**	**-0.1260**	**0.1608**	**-0.0673**
Cattle	0.0326	**-0.0652**	**0.1234**	-0.0362

Second canonical variable pair: In the canonical variable of the resultant variables insect byte - and pollen allergy are prevailing in decreasing order of importance with different signs (Table 6). Hence, there is a tendency that someone has one kind of allergy but misses the other. The most important explanatory variables are parquet (based on the signs, pollen allergy tends to occur with parquet flooring in the house) and obesity (being in an inverse and a proportional relationship with pollen- and insect byte allergies, respectively) (Tables 5-6).

Table 6 Correlations between target variables and canonical variables (**bold**, ***bold italic*** and *italic* refer to correlations different from zero at 99.9, 99 and 95% significance levels)

Target variables	Canonical variable			
	1		2	
	Males	Females	Males	Females
Dust	**0.7407**	**0.6440**	**-0.2999**	**0.9199**
Pollen	**0.7969**	**-0.2064**	**-0.4583**	-0.0101
Food	**0.1956**	**-0.1942**	**0.3018**	**0.1171**
Skin	**0.1182**	**-0.1191**	**0.3084**	*0.0393*
Pet	**0.6177**	0.0163	**0.0760**	**0.2602**
Medicine	**0.2320**	**0.2594**	**0.3047**	0.0314
Insect bite	-0.0104	**-0.3506**	**0.6585**	**0.0971**

3.2.3. Sensitive females

First canonical variable pair: The most relevant explanatory variables are vascular disease, urban apartment living and (with a smaller weight and opposite sign) family house living, in decreasing order of importance (Table 5). Based on this, vascular disease and urban apartment living are the main reasons of dust allergy symptoms, while family house living may facilitate insect byte allergy (Table 6).

Second canonical variable pair: In the canonical variable of the resultant variables practically the role of dust allergy is the most relevant (Table 6). The most remarkable explanatory variables are floor carpet and lung disease (Table 5). They both may provoke dust allergy. The role of parquet flooring is smaller with an opposite sign. Namely, this variable hinders developing dust allergy (Tables 5-6).

3.3. Factor analysis and special transformation

In order to determine the influence of the 26 explanatory variables considered on the 7 allergens (resultant variables), furthermore to calculate their weight in developing allergic diseases, factor analysis and then special transformation were performed for the age groups of younger individuals, adults and the elderly, furthermore for all sensitive individuals (males and females, total). Altogether 4 (3 age groups + total) x 3 (genders + total) x 7 (resultant variables) = 84 factor analyses and then 84 special transformations were performed.

Not all the results received from the 84 procedures according to the individual categories will be presented here. Instead, the effect of the 26 explanatory variables are only analysed for the age category of young males on all 7 resultant variables (allergens) (7 factor analyses and special transformations (Table 7). The development of dust allergy is substantially influenced by 9 explanatory variables. They are in decreasing order of importance: lung disease (with the same sign, +), diabetes (with opposite sign, –), the bedding material (feather, non-feather) (+), concrete wall of the housing (–), dog (–), high blood pressure (+), the flat floor carpet (–), heart disease (–) and brick wall of the housing (+). Explanatory variables with positive sign facilitate developing dust allergy, while those

Table 7 Special transformation. Effect of the explanatory variables on different allergens as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable; young males (15 years < age ≤ 24 years) (thresholds of significance: *italic:* $x_{0.05} = 0.070$; **bold:** $x_{0.01} = 0.092$)

Resultant variables / Explanatory variables	weight dust 0.950	rank –	weight pollen -0.921	rank –	weight food -0.949	rank –	weight skin -0.973	rank –	weight pet -0.965	rank –	weight medicine 0.982	rank –	weight insect bite 0.989	rank –
Breastfeeding (yes/no)	0.049	13	**0.126**	5	0.049	15	-0.005	24	-0.046	14	*-0.091*	3	-0.035	15
High blood pressure	**0.096**	6	-0.037	21	*0.078*	12	0.030	13	**-0.124**	4	0.047	14	-0.011	18
Vascular diseases	0.048	14	0.043	20	**-0.173**	2	**-0.101**	3	**-0.105**	5	**-0.102**	2	*-0.089*	2
Heart disease	*-0.084*	8	**-0.115**	7	0.067	14	0.006	22	**0.130**	2	*0.072*	8	0.052	11
Lung disease	**0.291**	1	**-0.345**	1	**-0.107**	7	**-0.093**	5	**-0.263**	1	0.064	11	-0.011	19
Diabetes	**-0.173**	2	*0.082*	12	**-0.094**	10	**-0.151**	2	0.067	9	0.019	21	0.006	21
Obesity	-0.064	11	-0.017	25	**-0.229**	1	-0.039	12	-0.052	11	-0.014	23	**0.092**	1
Cancer	0.063	12	**0.099**	10	**0.097**	9	*-0.090*	6	*0.082*	7	**0.129**	1	*0.078*	5
Alcohol (yes/no)	0.007	24	*-0.087*	11	**0.163**	3	*0.076*	8	0.059	10	0.023	20	-0.055	10
Smoking (yes/no)	0.003	25	**0.155**	3	**-0.118**	5	**-0.228**	1	-0.040	15	-0.038	16	0.017	17
Urban apartment living	0.041	15	**-0.102**	9	0.028	20	-0.049	10	-0.080	8	-0.069	9	-0.063	7
Live in apartment housing	0.001	26	0.050	18	**0.163**	3	*-0.082*	7	-0.001	26	-0.007	24	0.004	25
Family house living	-0.023	19	0.051	17	-0.006	24	0.025	14	0.034	16	*0.089*	5	0.005	22
Concrete wall of the housing	**-0.142**	4	0.063	15	**-0.099**	8	0.012	20	0.004	23	-0.051	13	0.000	26
Brick wall of the housing	*0.072*	9	**-0.107**	8	*0.088*	11	0.015	18	0.026	18	0.028	19	0.005	23
Adobe walls of the housing	0.030	17	**0.116**	6	0.032	18	-0.005	23	-0.004	24	0.047	15	-0.056	9
State of the housing walls (dry, wet)	0.067	10	**-0.178**	2	-0.041	17	-0.023	15	-0.009	22	-0.028	18	*0.087*	3
Parquet flooring in the house	0.018	22	*-0.076*	13	-0.027	21	0.000	26	0.025	19	-0.068	10	*-0.085*	4
The flat floor carpet	**-0.096**	7	*0.074*	14	*0.076*	13	-0.003	25	0.021	21	0.006	25	0.047	12
The flat floor stone	0.033	16	0.026	22	0.006	25	-0.015	17	0.047	13	-0.014	22	0.027	16
The bedding material (feather, non-feather)	**0.151**	3	-0.059	16	-0.045	16	0.020	16	**-0.103**	6	0.036	17	-0.038	14
dog	**-0.107**	5	**0.148**	4	-0.031	19	0.013	19	**0.129**	3	0.000	26	-0.009	20
cat	-0.028	18	-0.024	23	**-0.118**	6	**-0.096**	4	0.023	20	*-0.089*	6	0.004	24
chicken	0.009	23	0.004	26	-0.006	23	0.006	21	0.026	17	*-0.075*	7	0.057	8
pig	0.022	20	0.022	24	-0.012	22	-0.042	11	0.048	12	-0.058	12	0.046	13
cattle	0.020	21	0.048	19	0.000	26	-0.069	9	0.001	25	*0.090*	4	*-0.071*	6

with negative sign have an opposite effect. The development of pollen allergy is substantially influenced by 14 explanatory variables. They are (here and in all further specifications) in decreasing order of importance and with their sign, as follows: lung disease (+), the state of the housing walls (+), smoking (–), dog (–), breastfeeding (–), adobe walls of the housing (–), heart disease (+), brick wall of the housing (+), urban apartment living (+), cancer (–), alcohol (+), diabetes (–), parquet floor in the house (+), as well as the flat floor carpet (–). Food allergy is significantly influenced by 13 explanatory variables, namely: obesity (+), vascular disease (+), alcohol (–), live in apartment housing (–), smoking (+), cat (+), lung disease (+), concrete wall of the housing (+), cancer (–), diabetes (+), brick wall of the housing (–), high blood pressure (–), the flat floor carpet (–). Skin allergy is a function of only 8 explanatory variables, namely: smoking (+), diabetes (+), vascular disease (+), cat (+), lung disease (+), cancer (+), live in apartment housing (+) and alcohol (–). Pet allergy can be substantially explained by 7 explanatory variables. They are as follows: lung disease (+), heart disease (–), dog (–), high blood pressure (+), vascular disease (+), the bedding material (feather, non-feather) (+) and cancer (–). Medicine allergy is significantly influenced by 8 explanatory variables, namely: obesity (+), vascular disease (–), breastfeeding (–), cattle (+), family house living (+), cat (–), chicken (–) and heart disease +). Insect byte allergy is a function of 6 explanatory allergies. They are as follows: obesity (+), vascular disease (–), the state of the housing walls (dry, wet) (+), parquet flooring in the house (–), cancer (+) and cattle (–) (Table 7).

At the same time, the total factor loadings and their rank of importance for the explanatory and the resultant variables describe much more precisely the effect of environmental factors on allergic diseases (Tables 8a-b). Note that in this case the absolute values of the factor loadings are summarized; namely, their absolute effect (involving both their positive and negative effects) on the resultant variable is considered. Summing up factor loadings of each explanatory variable for the individual age categories according to the 7 resultant variables, will result in how they influence the developing of the different allergic diseases (Tables 8a-b). Based on this, the joint effect of the 26 explanatory variables for the three age groups of young individuals as well as for adult males influence mostly developing pollen allergy; while, for the remaining age groups of adults it operates principally in evolving dust allergy (Table 8a). The joint effect of all explanatory variables for elderly males provokes pollen allergy, for elderly females and all elderly food allergy, for all sensitive males and females pollen allergy, while for the total sensitive individuals all cases pet allergy (Table 8b).

4. DISCUSSION AND CONCLUSIONS

Several studies have analysed socio-demographic, environmental and genetic conditions of asthma and allergic rhinitis (e.g. du Prel et al., 2006, Mattei et al., 2007, Stallberg et al. 2007, Navarro et al. 2009, Batlles-Garrido et al. 2010).

Allergic diseases may have several socio-demographic, environmental and genetic components. Health effects of social inequalities can be demonstrated globally and it is an important public health problem (du Prel et al. 2006). Pollen (Mattei et al. 2007, Stallberg et al. 2007, Navarro et al. 2009). Dust mite (El-Sharif et al. 2003, Mattei et al. 2007, Navarro et al. 2009) and smoking parents (Mattei et al. 2007) belong to the most frequent environmental risk factors. Furthermore, the smoking of adolescents shows a significant association with wheeze (Mattei et al. 2007). In China, for those suffering from asthma and/or rhinitis the most frequent allergen is house dust mite (Li et al. 2009). For females living in the countryside and having lower education (Laforest et al. (2005), as well as for those belonging to lower income categories (Breton et al. 2006) there is a higher chance of allergic rhinitis. Several authors have demonstrated that explanatory variables analysed in this study are potential components of asthma and allergic rhinitis. For those living in the countryside and contact with farm animals (Waser et al. 2005, Batlles-Garrido et al. 2010), or have pets (Chen et al. 2008), allergic diseases develop rarely. At the same time, pet allergy can occur for sensitive individuals (Stallberg et al. 2007). Furthermore, females are exposed more intensely to asthma (Stallberg et al. 2007) and allergic rhinitis (Mattei et al. 2007, Todo-Bom et al. 2007), furthermore age, smoking (Stallberg et al. 2007), in addition wet housing walls and damp apartment are also risk factors for them (du Prel et al. 2006). Farm milk consumption ever in life showed a statistical inverse relationship with asthma. In this way the consumption of farm milk may offer protection against asthma and allergy (Waser et al. 2005). Fruit and fish consumption may reduce and fast food consumption may increase the risk for asthma (Norback et al. 2007). Wjst et al. (2005) found that overall allergic rhinitis decreased with geographical latitude. At the same time, no altered risk by birth month was found. They excluded major birth month effects and confirmed the independent effect of language grouping, reflecting genetic or cultural risk factors (Wjst et al. 2005).

Table 8a Total sum of the factor loadings of the explanatory variables for each age category, according to the resultant variables and their rank of importance in developing the individual effect of the 7 allergens

Age groups	[1]Young males		[1]Young females		[1]Young individuals, total		[2]Adult males		[2]Adult females		[2]Adults, total	
Resultant variables	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank
Dust	1.738	3	1.808	4	1.882	3	1.436	6	2.544	1	2.116	1
Pollen	2.254	1	2.198	1	2.562	1	2.444	1	2.395	2	2.067	2
Food	1.953	2	1.913	2	1.517	4	1.944	3	1.237	5	1.085	5
Skin	1.294	6	1.898	3	1.488	5	1.290	7	0.867	7	0.841	7
Pet	1.549	4	1.630	6	2.172	2	2.017	2	2.152	3	1.937	3
Medicine	1.354	5	1.516	7	1.373	6	1.536	5	1.159	6	1.079	6
Insect bite	1.050	7	1.703	5	1.167	7	1.818	4	1.282	4	1.298	4

[1]: 15 yr < age ≤ 24 yr; [2]: 25 yr < age ≤ 54 yr

Though the above risk factors do not cover totally the scope of the selected 26 factors potentially facilitating asthma and allergic rhinitis, they indicate the diversity of the potential effects.

Summing up our results, those suffering from lung disease are significantly more sensitive to at least one allergen, while among those living in family house or contact with chickens or pigs, the number of sensitive individuals is substantially smaller. In the case of young individuals, the ratio of females suffering from any kind of allergy is remarkably higher compared to males. In the same way, elderly females are more sensitive to any allergen compared to elderly males.

Table 8b Total sum of the factor loadings of the explanatory variables for each age category, according to the resultant variables and their rank of importance in developing the individual effect of the 7 allergens

Age groups / Resultant variables	[1]Elderly males		[1]Elderly females		[1]Elderly, total		Total sensitive individuals, males		Total sensitive individuals, females		Total sensitive individuals, all	
	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank	Factor loading	Rank
Dust	3.028	2	2.454	4	1.816	5	0.983	6	2.140	2	0.864	6
Pollen	3.448	1	2.136	5	1.932	4	2.304	1	2.287	1	1.065	2
Food	2.984	4	3.043	1	2.163	1	1.450	2	1.161	5	1.050	3
Skin	2.741	7	2.472	3	1.807	6	1.144	5	1.252	4	1.041	4
Pet	2.987	3	2.871	2	1.941	3	0.974	7	1.914	3	1.493	1
Medicine	2.873	6	1.997	6	1.981	2	1.398	3	1.097	6	0.810	7
Insect bite	2.879	5	1.538	7	1.300	7	1.192	4	0.991	7	0.942	5

[1]: age > 54 yr

Applying canonical correlation we found that for sensitive males the most important explanatory variables are lung disease and the bedding material (feather, non-feather) substantially contributes to developing pollen-, dust- and pet allergy. For sensitive females vascular disease and urban apartment living are the most relevant risk factors, mostly provoking dust allergy. Regarding all sensitive individuals, the role of the bedding material (feather, non-feather) and lung disease are the most remarkable; mostly they generate pollen-, dust- and pet allergy.

Using factor analysis and special transformation it was established that for young males the explanatory variables are substantially more efficient in developing pollen- and food allergy than in provoking insect byte allergy. Furthermore, the explanatory variables are remarkably more efficient in developing dust allergy for adult females than for adult males. In addition, both for adult males and females the explanatory variables affect skin allergy to a significantly smaller degree than pet allergy. The most evident result is that the explanatory variables affect each type of allergy for the elderly to a remarkably smaller degree compared to those of the remaining age groups.

It was found that for young individuals vascular and lung diseases are especially effective reasons of allergic diseases; however, heart disease, obesity, alcohol, smoking, the bedding material (feather, non-feather) and dog are also important influencing factors. For adults, high blood pressure, smoking, type and state of the housing walls are the dominant parameters. For the elderly, the environmental factors affect developing allergic diseases much less compared to the remaining two age groups. For elderly females cancer and alcohol are the most relevant risk factors.

The joint effect of the 26 explanatory variables for all three age groups of young individuals and for adult males explains mostly developing pollen allergy, while for the remaining age groups of adults it basically operates through provoking dust allergy. The joint effect of all explanatory variables for elderly males influences fundamentally pollen allergy, for elderly females and all the elderly food allergy, for all sensitive males and females pollen allergy, while for the total sensitive individuals all cases pet allergy.

When summing up factor loadings of each explanatory variables for the individual age categories according to the 7 resultant variables, the most important components of allergic diseases are as follows: for young males heart and lung disease, for young females lung disease and cattle, while for all young individuals lung disease and smoking. For adult males, females and all adults lung disease is ranked first,whereas heart disease, the bedding material (feather, non-feather) and the state of the housing walls (dry, wet) are the second most important component. For elderly males family house living and urban apartment living are the most relevant risk factors. For elderly females the role of alcohol and cancer is the most substantial, while for all the elderly alcohol and diabetes are the most important explanatory variables. For total sensitive males, females and all cases lung disease is the most dominant factor, while smoking, the bedding material (feather, non-feather) and cattle are the second most relevant components of allergic diseases, respectively.

If sensitivity is detected at an individual to any socio-demographic or environmental factor, then by its conscious modification and/or a changing the way of life one can take decisive steps for preventing allergic diseases or for handling a developed sensitivity.

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ASSOCIATION OF EXTREME HIGH AND LOW TEMPERATURES AND PRECIPITATION TOTALS WITH DAILY AND ANNUAL POLLEN CONCENTRATIONS OF AMBROSIA AND POPULUS IN SZEGED, SOUTHERN HUNGARY

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Summary: The aim of this study is to analyse the associations between pollen characteristics and extreme values of meteorological variables, furthermore to make an association between the rank of pollen characteristics and the rank of annual values of meteorological variables for Szeged in Southern Hungary. Pollen season (start, end and duration), as well as pollen quantity (total annual pollen amount, i.e. TPA and annual peak pollen concentration) characteristics, furthermore data sets of temperature and precipitation are considered for a 14-year period (1997-2010). The data set also contains daily values of *Ambrosia* (ragweed) and *Populus* (poplar) pollen concentrations, as well as temperature and precipitation. Correlation analysis between the original variables and between their ranks was performed. We received that both taxa were sensitive either to temperature or precipitation. On the whole, due to a warming and drying climate, pollen quantity characteristics indicate a decrease for *Ambrosia*, while for *Populus* an increase is expected.

Key words: *Ambrosia, Populus,* pollen counts, pollination period

1. INTRODUCTION

The weather-related daily variability of pollen concentrations has a wide range of literature. Some of them study the relationship of meteorological parameters and daily pollen concentrations (e.g. Bartková-Ščevková 2003, Rodríguez-Rajo et al. 2005, Štefanič et al. 2005, Kasprzyk 2008, Recio et al. 2010). While others, based on meteorological data, use different techniques for predicting pollen characteristics (e.g. Galán et al. 2001, Aznarte et al. 2007, García-Mozo et al. 2009).

The role of extreme weather events to daily pollen concentrations has so far received little attention. Frei (2004, 2006) studied the co-occurrences of extreme events (storms, floods or droughts) with extreme birch and grass pollen concentrations in the data set of Basel. The heat wave over Europe in summer 2003 with mean temperature exceeding the 1961-1990 mean by about 5°C in June, July and August substantially influenced pollen phenology and pollen production in Switzerland (Gehrig 2006). The grass pollen season was most affected starting 1-2 weeks earlier and ending 7-33 days earlier than in general. Extremely high *Chenopodium*, *Plantago* and Poaceae daily pollen concentrations were measured in that pollen season. Cariñanos et al. (2000) analyzed the yearly distribution and severity of *Artemisia* and Chenopodiaceae-Amaranthaceae pollen load indicating the highest and very high pollen levels in a rural area with sub-desert climate and extreme dryness. Hart et al. (2007) analysed the effect of the six warmest months to the pollen concentrations in Sydney, Australia.

In climatology, several criteria are used to classify extreme events. (1) Rare events: they occur with relatively low frequencies. For example, the IPCC (2001) defines an "extreme weather event" to be "an event that is rare within its statistical reference distribution at a particular place. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. (2) Intense events: they are characterized by relatively small or large values (i.e. events that have large magnitude deviations from the normal). Not all intense events are rare: for example, low precipitation totals are often far from the mean precipitation but can still occur quite frequently. Intensity as defined here should not be confused with the definition of intensity used in the literature to denote the frequency/rate of events (Beniston et al. 2007). (3) Severe events: they result in large socio-economic losses. Severity is a complex criterion because damaging impacts can occur in the absence of a rare or intense climatic event: for example, thawing of mountain permafrost leading to rock falls and mud-slides (Beniston et al. 2007).

As an example, a heat wave event occurs on a day if the air temperature is larger than the normal daily mean plus one or more standard deviations (Baldi et al. 2005). Short-lasting (3 to 6 days) or long-lasting (6 or more consecutive days) heat (cool) waves have been defined when the temperature exceeds the 90th percentile (is below the 10th percentile) on the given days (Tank and Konnen 2003).

However, due to the recent climate change, the variability of temperature and precipitation increase (Tank and Konnen 2003) and extreme weather events (e.g. cold or hot days, as well as droughts or rainy periods) can be persistent; they can last several weeks and even they can be repeated several times. Global warming may facilitate to extend habitats of certain herbaceous and arboreal plants contributing to the increase of pollen levels and exacerbation of their adverse effects, hence to the rise of pollen sensitivity and respiratory admissions due to a pollen allergy (D'Amato and Cecchi 2008, Ariano et al. 2010, Ziska et al. 2011). Thus, the analysis of the effects of long-lasting extreme weather events on the daily or annual pollen concentrations is of ever increasing importance.

The purpose of this paper is to analyse the associations between pollen characteristics and meteorological variables, furthermore between the rank of ordered pollen characteristics and the rank of ordered annual values of meteorological variables for Szeged in Southern Hungary. Based on these results, a potential change in the pollen amount is concluded due to global warming.

2. MATERIALS

Szeged (46.25°N; 20.10°E), the largest settlement in Southern Hungary is located at the confluence of the rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m AMSL. The city is the centre of the Szeged region with 203,000 inhabitants. The climate of Szeged belongs to Köppen's *Ca* type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Makra et al. 2008).

Meteorological data were collected in the meteorological monitoring station (operated by the Environmental and Natural Protection and Water Conservancy Inspectorate of the Lower-Tisza Region, Szeged) located in the downtown of Szeged at a distance of about 10 m from the busiest main road.

In order to determine the association between extreme high and low temperatures and precipitation totals on one hand and pollen counts of the two taxa selected on the other, daily values of two meteorological variables (mean temperature and precipitation total) and daily pollen concentrations of *Ambrosia* (ragweed) and *Populus* (poplar) were considered. Selection of the above two taxa is justified by their high and medium allergenicity [in a four-score scale (www.pollenindex.hu); the allergenicity of *Ambrosia* is the highest indicated by score 4, while that of *Populus* is medium indicated by score 2] and their more or less permanently high pollen concentrations. They belong to the two highest pollen levels of all taxa measured for the period examined, namely *Ambrosia* (32.3%) and *Populus* (9.6%) together account for 41.9% of the total pollen production. (Annual pollen production of Poaceae (10.5%) is the 2nd highest of all taxa considered in Szeged area.)

Ambrosia genus has only one species, namely *Ambrosia artemisiifolia* (Common Ragweed) in the Szeged region. This appears both in the urban environment and in the countryside. Ragweed occurs especially frequently west of the city. The ruling north-western winds can easily transport pollen into the city. Since in the sandy region, northwest of Szeged, stubble stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can spread unchecked. Owing to newly-built motorways around Szeged, several farmland areas have been left untouched for a long time that also favour the expansion of *Ambrosia*. For the *Populus* genus, natural species of *Populus alba* (White Poplar) and *Populus canescens* (Grey Poplar), as well as cultivated poplars such as I-273 Poplar and *Populus x euroamericana* (Canadian Poplar) and its variants are the most frequent in the city.

The analysis was performed for the 14-year period 1997-2010. The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains m^{-3} (Galán et al. 2001). Evidently, the pollen season for both pollen types varies from year to year.

3. RESULTS

The periods examined for the two taxa are indicated by the days of the year, namely: for *Ambrosia* days 132-280 and for *Populus* days 35-113. The end of these periods was selected according to the average end date of the pollination seasons. Starting day (132, 62 and 35) was identical with the starting date for calculating cumulated daily mean temperatures used as a predictor for the estimation of the start of the pollen season. Such a date is chosen as to minimise the mean squared error of estimated pollen season starts (Laaidi et al. 2003).

Daily mean temperatures and daily precipitation amounts were cumulated over these above mentioned periods for every year separately corresponding to the two taxa. These quantities were then related to annual pollen characteristics. Additionally, the annual course of both daily mean temperature and daily precipitation amount was described by fitting sine and cosine waves of one year and one half year periods to the entire 14-year data set. The one half year period was used to reproduce the asymmetry of the annual cycle. The mean squared deviation (MSD) between actual daily mean temperatures/precipitation amounts and the annual course was calculated for each year for the periods according to the two taxa. MSD values were then ordered from the highest to lowest values. These ranks of years were related to ranks of ordered annual pollen characteristics.

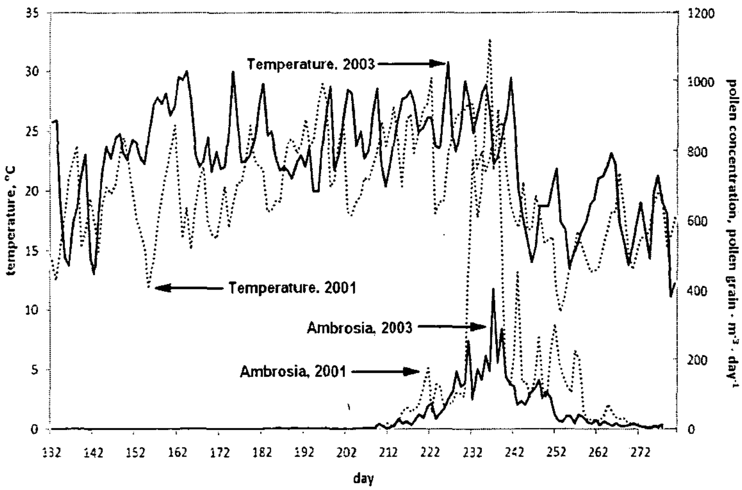
Correlations between the rank of pollen characteristics and the rank of years based on temperature and precipitation were calculated for both taxa. In a first approach, correlations were determined for every year, and then they were computed for the three warmest and coldest as well as for the three wettest and driest years (extreme years), respectively (Table 1). As the number of data for calculating correlations is very small (14 or just 6) the interval for accepting the null-hypothesis of correlation zero was determined as follows. N values of meteorological variables (cumulated temperature, cumulated precipitation, ranks of MSDs) corresponding to the N years were reordered while keeping the pollen characteristics. Correlation between these two new data sets was then calculated. Reordering and computation of the correlation were done in every possible case except for the original non-reordered case. Having (N!-1) number of correlations, the interval to be found is $(q_\varepsilon, q_{1-\varepsilon})$, where q_ε is the ε-quantile of these correlations.

Table 1 Correlations between the rank of pollen characteristics and the rank of years based on temperature and precipitation. TPA: Total Pollen Amount during the pollination season, APC: Annual Peak Concentration, SPS: Start of the Pollination Season, EPS: End of the Pollination Season, DPS: Duration of the Pollination Season. Significance levels for correlations being non-zero are shown in parentheses for levels no higher than 10%.

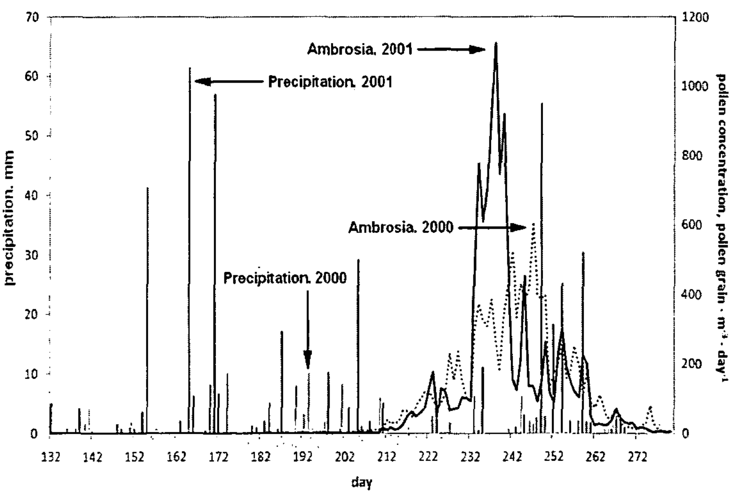
Pollen characteristics, taxa	Temperature		Precipitation	
	Every year	*6 years	Every year	*6 years
TPA, *Ambrosia*	-0.39	**-0.88** (1.8%)	0.24	0.28
APC, *Ambrosia*	**-0.51** (6%)	**-0.97** (0.2%)	0.38	0.61
SPS, *Ambrosia*	0.20	0.09	0.17	0.26
EPS, *Ambrosia*	-0.27	-0.07	-0.07	-0.02
DPS, *Ambrosia*	-0.35	-0.20	-0.15	-0.20
TPA, *Populus*	0.22	0.11	0.16	0.42
APC, *Populus*	0.12	-0.16	0.14	0.31
SPS, *Populus*	**-0.59** (3%)	**-0.72** (10%)	-0.07	-0.21
EPS, *Populus*	-0.36	**-0.77** (8%)	-0.15	-0.10
DPS, *Populus*	**0.46** (10%)	0.56	0.00	0.33

*6 years: the three warmest / coldest and the three wettest / driest years, respectively

For *Ambrosia*, only temperature related correlations are relevant. When considering every year, the rank of annual peak concentrations (APC) is inversely proportional to the rank of the annual temperature data. While, for the extreme years, the ranks of both the total pollen amount (TPA) and the APC are negatively associated with the rank of the annual temperature data. In more detail, in the warmest year, TPA was the 2nd smallest and APC the 3rd smallest. In the coldest year, TPA was the 2nd highest and the APC was the 3rd highest (Table 1, Fig. 1).



a
days of the year examined: 132-280
warmest year 2003; coldest year: 2001



b
days of the year examined: 132-280
wettest year: 2001, driest year: 2000

Fig. 1 Daily pollen concentrations of *Ambrosia*, in years with extreme temperature and precipitation

For *Populus*, only temperature-related substantial correlations have been detected. When considering every year, ranks for both the start of the pollination season (SPS) and the duration of the pollination season (DPS) are associated with the rank of the annual temperature data. Taking into account only the extreme years, the ranks of both the SPS and the end of the pollination season (EPS) are inversely proportional to the rank of the annual temperature data. In more detail, in the warmest year the DPS was the 3rd longest, while in the coldest year it was the 5th shortest. In the coldest year the SPS was the 2nd latest, while in the warmest year it was the earliest (Table 1, Fig. 2).

Correlations between the pollen characteristics and the cumulated daily values of meteorological variables (temperature and precipitation) are summarised in Table 2. For *Ambrosia*, only temperature-related associations are important. Similarly to the ranks when considering every year, the correlation between the APC and the temperature is inversely proportional. For the extreme years, both the TPA and the APC are in substantial negative connection with temperature (Table 2, Fig. 1). For *Populus,* precipitation based associations are irrelevant, but for the extreme years, the EPS is in significant negative correlation with temperature (Table 2, Fig. 2).

Table 2 Correlations between pollen characteristics and meteorological variables. TPA: Total Pollen Amount during the pollination season, APC: Annual Peak Concentration, SPS: Start of the Pollination Season, EPS: End of the Pollination Season, DPS: Duration of the Pollination Season. Significance levels for correlations being non-zero are shown in parentheses for levels no higher than 10%.

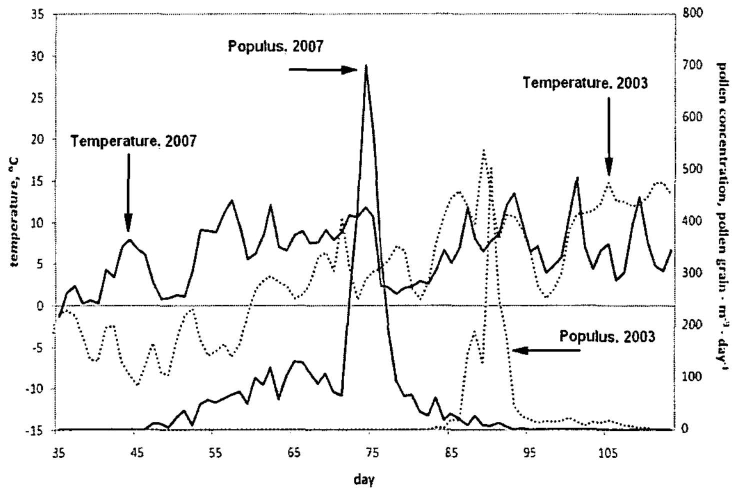
Pollen characteristics,	Temperature		Precipitation	
taxa	Every year	*6 years	Every year	*6 years
TPA, *Ambrosia*	-0.39	**-0.81** (5%)	0.15	0.14
APC, *Ambrosia*	**-0.49** (8%)	**-0.90** (1%)	0.43	0.67
SPS, *Ambrosia*	0.16	0.05	0.39	0.56
EPS, *Ambrosia*	-0.25	-0.22	0.00	0.06
DPS, *Ambrosia*	-0.28	-0.32	-0.23	-0.42
TPA, *Populus*	0.20	-0.09	0.20	0.61
APC, *Populus*	0.13	-0.37	-0.04	0.39
SPS, *Populus*	-0.04	-0.71	-0.07	-0.26
EPS, *Populus*	-0.16	**-0.81** (5%)	-0.16	0.01
DPS, *Populus*	-0.08	0.56	-0.08	0.36

*6 years: the three warmest / coldest and the three wettest / driest years, respectively

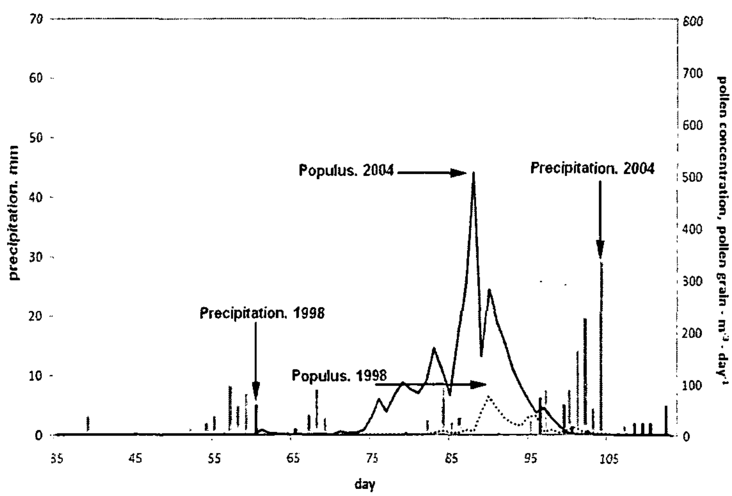
4. DISCUSSION AND CONCLUSIONS

A moderate warming is favourable for *Ambrosia* (Ziska et al. 2011). The increase of mean temperature can restrict the ability of the heat tolerant *Ambrosia* to pollinate, especially in summer time (August), since the plant concentrates on preserving water and maintaining its vegetative life functions rather than generative functions. This is in accordance with the negative association between its pollen count characteristics (TPA and APC) and temperature (Tables 1-2). This genus can adapt well to dry and hot conditions, but is highly influenced by future land use. If more fallows and abandoned human habitats appear in the landscape its further increase can be expected especially on sand soils (Deák 2010) in spite of the expected warming and drying summers in the Carpathian basin (Bartholy et al. 2008).

The plantation of *Populus* species has not stopped during the last 10 years. Besides locust-tree *(Robinia pseudo-acacia)*, they are the most favoured trees of afforestations in the Szeged region. The stands planted during the last decades have grown up, they are in a mature state, so they can pollinate on a high level. Warmer, moderately humid weather in the spring also favours their pollination. Since *Populus* has both drought and heat tolerant species from floodplains to bare sand they have high environmental tolerance. Furthermore, they have low climate sensitivity (Deák 2010). However, the discrepancy between their low climate sensitivity on one hand and a remarkably earlier start (Table 1), later end (Tables 1-2), as well as longer duration (Table 1) of their pollen season on the other should be justified. A warming and drying climate is more favourable for them in general, facilitating their higher pollen release. Hence, a changing climate (warming and drying) may partly contribute to an extension of the pollen season (Tables 1-2) (Caramiello et al. 1994).



a
days of the year examined: 35-113
warmest year 2007; coldest year: 2003



b
days of the year examined: 35-113
wettest year: 2004, driest year: 1998

Fig. 2 Daily pollen concentrations of *Populus*, in years with extreme temperature and precipitation

Based on our data set, both taxa are sensitive either to temperature or precipitation. On the whole, due to a warming and drying climate expected in the Carpathian basin (Bartholy et al. 2008) pollen count characteristics (TPA and APC) indicate a decrease for *Ambrosia*, while for *Populus* an increase is expected. Concerning *Ambrosia*, the effect of its area increase, due to change in land use, on its pollen release is smaller than the effect of its heat stress in hot summers restricting its ability to pollinate. As a result, global warming may involve a decrease in the pollen count characteristics of *Ambrosia*.

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INFLUENCE OF METEOROLOGICAL ELMENTS TO INTERDIURNAL VARIABILITY OF RAGWEED (AMBROSIA) POLLEN CONCENTRATIONS

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Summary: The purpose of the study is to analyze the potential reasons of day-to-day variations of *Ambrosia* pollen counts for the Szeged region of Southern Hungary in association with meteorological elements. The database includes a ten-year period (1997-2006) comprising the daily ratios of Ambrosia pollen counts (A) (value on the given day per value on the day before) for its pollen season (July 15 – October 16). At the same time, daily values (value on the given day – value on the day before) of 8 meteorological variables (mean temperature, minimum temperature, maximum temperature, temperature range, irradiance, relative humidity, wind speed and rainfall) are considered for the period April 1 – October 31, 1997-2006. When using a novel procedure, factor analysis with special transformation, wind speed, rainfall and temperature range are the most relevant, while minimum temperature and irradiance are the least important meteorological variables influencing daily pollen ratios. Namely, the data set for which A≤1.00 can be associated to lower summer temperatures with near-optimum phyto-physiological processes, while the category A>1.00 is involved with high and extreme high temperatures modifying life functions and, hence, interrelationships of the meteorological and pollen variables.

Key words: ragweed, allergenic pollen, respiratory disease, meteorological elements, physiological processes, pollen transport

1. INTRODUCTION

Air pollution, as a major and ever increasing hazard for the environment, is associated with persistent increases in expenses of social insurance (Cohen et al. 2005). The prevalence of allergic respiratory diseases has also increased extensively during the last three decades, (D'Amato 2002). An examination of the historical record demonstrated that the prevalence of allergic rhinitis and allergic asthma have significantly increased over the past two centuries. Although the reasons for this increase are not fully disclosed, epidemiologic data presume that particular pollutants produced from the burning of fossil fuels may have played a substantial role in the prevalence changes (Peterson and Saxon 1996).

Pollen allergy has become a widespread disease by the end of the 20th century. Recently, around 20% of the population, as an average, suffers from this immune system disease in Europe (D'Amato et al. 2007). Hungary is exposed to one of the most severe air pollution in Europe (Ågren 2010); in addition, airborne pollen levels here are also high. The Carpathian basin, comprising Hungary is considered the region most polluted with airborne ragweed (*Ambrosia*) pollen in Europe (Štefanič et al. 2005, Peternel et al. 2006, Ianovici and Sîrbu 2007, Šikoparija et al. 2009, Chrenová et al. 2010). *Ambrosia* in Hungary discharges the most pollen of all taxa (Járai-Komlódi and Juhász 1993, Makra et al. 2004); the ratio of its pollen release compared to the total pollen release in the late summer period is around 60-71% in Szeged (Juhász and Juhász 2002). Highest counts on peak days in Szeged, Southern Hungary, are about one order of magnitude higher than those over other cities in Europe (Makra et al. 2005). The sensitivity of patients to ragweed in Szeged is 83.7% (Kadocsa and Juhász 2000). Ragweed-related allergy and asthma have become the dominant disease in Hungary during the past few decades (Kazinczi et al. 2008, Páldy et al. 2010). Recently, 20% of the total population suffers from allergic illnesses and for one-third of these patients asthma can also be diagnosed (Strausz et al. 2009). 60-90% of patients with pollen allergy are exposed to ragweed allergy (Harsányi 2009). The number of patients with registered allergic illnesses has doubled and the number of cases of allergic asthma has become four times higher in Southern Hungary by the late 1990s over the last 40 years (Makra et al. 2004).

In the knowledge of its weather-dependence, the analysis of association of daily ragweed pollen concentrations with daily meteorological parameters is of great practical importance. Applying simple statistical analysis, several studies have detected significant positive correlations between daily ragweed pollen counts on one hand and daily maximum temperature (Stepalska et al. 2008), daily mean temperature (Bartkova-Scevkova 2003, Štefanič et al. 2005, Peternel et al. 2006, Puc 2006, Kasprzyk 2008), daily mean wind speed (Kasprzyk 2008) and daily maximum wind speed (Puc 2006) on the other, but negative correlations with relative humidity (Bartkova-Scevkova 2003, Puc 2006, Kasprzyk 2008) and rainfall (Peternel et al. 2005, Peternel et al. 2006, Kasprzyk 2008). Furthermore, Ziska et al. (2003) established that higher urban temperatures were associated with higher ragweed pollen counts at urban sites compared to rural locations. Based on wind direction analysis, in given cases either long range transport or local sources could have played an important role in actual ragweed pollen concentrations (Kasprzyk 2008, Stepalska et al. 2008).

However, meteorological elements affect pollen concentration not by means of their individual values but through their interrelationships. Accordingly, it is practical to study the association of daily ragweed pollen concentration with daily values of meteorological elements as a whole. Only relatively few papers have reported results of such approaches using multivariate statistical analysis techniques. They generally define the most homogeneous groups as objective classes of meteorological elements (Makra et al. 2006, Hart et al. 2007, Makra et al. 2008, Tonello and Prieto 2008) using factor and cluster analyses in order to associate them with a given pollen variable.

The aim of the study is to analyze the potential reasons of day-to-day variations of *Ambrosia* pollen counts for the Szeged region of Southern Hungary in association with meteorological elements. Studying day-to-day variations of ragweed can be considered specific, since we have not found such papers in the international literature. Neither has *Ambrosia* pollen, the most allergenic pollen type, been studied from this point of view. For this purpose, a factor analysis with special transformation is performed on the daily meteorological and *Ambrosia* pollen data in order to find out the strength and sign of associations between meteorological (explanatory) variables and *Ambrosia* pollen (resultant) variable. Factor analysis with special transformation is a unique procedure in the special literature that has not yet been applied for this kind of task.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N; 20.10°E) is the largest settlement in South-eastern Hungary. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above mean sea level. The built-up area covers a region of about 46 km^2. The city is the centre of the Szeged region with 203,000 inhabitants. In the Köppen system the climate of Szeged is the *Ca* type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located about 20 m above the ground.

The analysis was performed for the ten-year period 1997-2006. Within this term, daily *Ambrosia* pollen counts were analysed for its pollen season (July 15 – October 16). At the same time, daily values of 8 meteorological variables [mean temperature, T_{mean}; minimum temperature, T_{min}; maximum temperature, T_{max}; temperature range, as the difference of maximum and minimum temperatures, $\Delta T(=T_{max}-T_{min})$; irradiance, I; relative humidity, RH; wind speed, V and rainfall, R] were considered between April 1 and October 31 for the above-mentioned 10-year period.

The *Ambrosia* genus has only one species, namely *Ambrosia artemisiifolia* (Common Ragweed) in the Szeged region. This appears both in the urban environment and in the countryside. Ragweed occurs especially frequently west of the city. The ruling north-western winds can easily transport pollen into the city. Since in the sandy region northwest of Szeged stubble stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can spread unchecked. Owing to newly-built motorways around Szeged, several farmland areas have been left untouched for a long time that also favour the expansion of *Ambrosia.*

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which at least 1 pollen grain $\cdot$ m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains m^{-3} (Galán et al. 2001). Evidently, the pollen season varies from year to year. Here the longest observed pollen season during the ten-year period was considered for each year, even if the remaining years involve substantially different pollen seasons with either a remarkably later start or a notably earlier end of the pollen release.

2.2. Factor analysis with special transformation

Factor analysis identifies any linear relationships among subsets of examined variables and this helps to reduce the dimensionality of the initial database without substantial loss of information. First, a factor analysis was applied to the initial dataset consisting of 8 variables (7 meteorological parameters as explanatory variables and daily ratios of *Ambrosia* pollen counts as resultant variable) in order to transform the original variables to fewer variables. These new variables (called factors) can be viewed as latent variables explaining the joint behaviour of meteorological – *Ambrosia* pollen variables. The optimum number of retained factors can be determined by different statistical criteria (Jolliffe 1993). The most common and widely accepted one is to specify a least percentage

(80%) of the total variance in the original variables that has to be achieved (Liu 2009). After performing the factor analysis, a special transformation of the retained factors was made to discover to what degree the above-mentioned explanatory variables affect the resultant variable, and to give a rank of their influence (Jahn and Vahle 1968). When performing factor analysis on the standardized variables, factor loadings received are correlation coefficients between the original variables and, after rotation, the coordinate values belonging to the turned axes (namely, factor values). Consequently, if the resultant variable is strongly correlated with the factor; that is to say, if the factor has high factor loading at the place of the resultant variable, and within the same factor an influencing variable is highly correlated with the factor, then the influencing variable is also highly correlated with the resultant variable. Accordingly, it is advisable to combine all the weights of the factors, together with the resultant variable, into one factor. Namely, it is effective to rotate so that only one factor has great load with the resultant variable. The remaining factors are uncorrelated with the resultant variable; that is to say, are of 0 weight (Jahn and Vahle 1968). This latter procedure is called special transformation.

3. RESULTS

For each day of the analysis daily differences in meteorological variables (value on the given day – value on the day before) were assigned to the daily ratios of *Ambrosia* pollen counts (A) (value on the given day per value on the day before). Three data sets were subjected to an analysis: (1) the total data set, (2) those daily differences in meteorological variables for which $A \leq 1$ and (3) those for which $A > 1$, respectively. For all three data sets, the days examined were classified into four categories, respectively. These categories are as follows: (a) rainy day, preceded by a rainy day; (b) rainy day, preceded by a non-rainy day; (c) non-rainy day, preceded by a rainy day; (d) non-rainy day, preceded by a non-rainy day.

After performing a factor analysis on all three data sets (altogether 3x4=12 factor analyses) (Tables 1-3), 4, 5, 4 and 4 factors were retained for (a), (b), (c) and (d) categories in the total data set (Table 1); 4, 5, 3 and 4 factors were considered for (a), (b), (c) and (d) categories in the data set for which $A \leq 1$ (Table 2); while, for the remaining case (in the data set for which $A > 1.00$) altogether 4 factors were retained for each category, respectively (Table 3). In order to calculate the rank of importance of the explanatory (meteorological) variables for determining the resultant variable (daily ratios of *Ambrosia* pollen counts), loadings of the retained factors were projected onto Factor 1 for all 12 factor analyses with a special transformation (Tables 1-3) (Jahn and Vahle 1968).

The relationships between the meteorological and pollen variables are only analysed for all data sets that were significant at 10%, 5% or 1% probability levels. Considering the total data set (Table 1), for category (a) rainfall (R), maximum temperature (T_{max}), mean temperature (T_{mean}) and temperature range (ΔT) in decreasing order of their importance are the most important variables denoting a proportional association with the daily ratios of *Ambrosia* pollen counts. At the same time, wind speed (V) indicates a weak inverse connection with the resultant variable. For category (b) rainfall (R) and wind speed (V) are the only relevant meteorological parameters, both inversely influencing the resultant variable. For category (c) no significant explanatory variables occur, while for category (d) only the role of relative humidity (RH) is substantial representing an inverse association with daily pollen ratios (Table 1).

Table 1 Special transformation. Effect of the daily differences in meteorological variables[1] on the daily ratios of *Ambrosia* pollen counts (A)[2], as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable, total data set (thresholds of significance: *italic:* $x_{0.10}$; **bold:** $x_{0.05}$; **bold:** $x_{0.01}$)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A)							
	a		b		c		d	
	thresholds of significance							
	0.139		*0.140*		*0.139*		*0.073*	
	0.165		**0.166**		**0.166**		**0.087**	
	0.217		**0.218**		**0.218**		**0.115**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	0.869	–	0.895	–	0.999	–	0.988	–
T_{mean}	**0.250**	3	0.118	3	0.083	2	-0.023	6
T_{min}	-0.029	8	0.063	6	0.117	1	0.059	3
T_{max}	**0.263**	2	0.074	4	0.049	4	-0.007	7
ΔT	**0.199**	4	-0.009	8	-0.082	3	-0.058	4
I	0.108	6	-0.069	5	0.029	6	-0.071	2
RH	0.092	7	0.056	7	0.046	5	**-0.166**	1
V	*-0.165*	5	**-0.291**	2	0.002	7	-0.034	5
R	**0.548**	1	**-0.359**	1	–	–	–	–

[1]: value on the given day – value on the day before; [2]: value on the given day per value on the day before; a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day; c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day;
T_{mean} = daily mean temperature; T_{min} = daily minimum temperature, T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance, RH = relative humidity; V = wind speed; R = rainfall

Regarding the data set for which daily ratios of *Ambrosia* pollen counts are smaller or equal to unit ($A \leq 1$) (Table 2), for category (a) rainfall (R) and wind speed (V) proportionally, while temperature range (ΔT) and mean temperature (T_{mean}) inversely influence the resultant variable. For category (b) wind speed (V) is the only substantial parameter indicating a positive association with daily pollen ratios. For category (c) wind speed (V) and minimum temperature (T_{mean}) are in an inverse, while temperature range (ΔT) and maximum temperature (T_{max}) are in a proportional association with daily ratios of *Ambrosia* pollen counts. For category (d) mean temperature (T_{mean}), maximum temperature (T_{max}), relative humidity (RH) and temperature range (ΔT) inversely, while irradiance (I) and wind speed (V) proportionally influence the resultant variable.

Concerning the data set for which daily ratios of *Ambrosia* pollen counts are higher than unit ($A \leq 1$) (Table 3), for category (a) a proportional association of rainfall (R), while for category (b) an inverse association of wind speed (V) and rainfall (R) with daily pollen ratios are the most important. For category (c) temperature range (ΔT) is negatively, while minimum temperature (T_{mean}) is positively associated with the resultant variable. For category (d) irradiance (I) and relative humidity (RH) are the most important, both inversely influencing daily pollen ratios.

Table 2 Special transformation. Effect of the daily differences in meteorological variables[1] on the daily ratios of *Ambrosia* pollen counts (A)[2], A ≤ 1.00 as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable, (thresholds of significance: *italic:* $x_{0.10}$; **bold:** $x_{0.05}$; **bold:** $x_{0.01}$)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A), A ≤ 1.00							
	a		b		c		d	
	thresholds of significance							
	0.185		*0.197*		*0.191*		*0.106*	
	0.220		**0.233**		**0.225**		**0.126**	
	0.286		**0.304**		**0.294**		**0.167**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	-0.790	–	-0.813	–	0.656	–	-0.929	–
T_{mean}	*0.193*	4	0.087	5	0.181	5	**0.260**	1
T_{min}	-0.166	6	0.165	2	**-0.316**	4	-0.023	7
T_{max}	0.170	5	0.027	8	**0.397**	3	**0.234**	2
ΔT	**0.249**	2	-0.129	4	**0.553**	2	**0.151**	4
I	0.000	8	-0.156	3	0.160	6	**-0.144**	5
RH	-0.072	7	-0.064	6	-0.084	7	**0.176**	3
V	**-0.243**	3	**-0.657**	1	**-0.631**	1	*-0.119*	6
R	**-0.725**	1	-0.058	7	–	–	–	–

[1]: value on the given day – value on the day before; [2]: value on the given day per value on the day before; a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day; c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day;
T_{mean} = daily mean temperature; T_{min} = daily minimum temperature, T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance, RH = relative humidity; V = wind speed; R = rainfall

Table 3 Special transformation. Effect of the daily differences in meteorological variables[1] on the daily ratios of *Ambrosia* pollen counts (A)[2], A > 1.00 as resultant variables and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable, (thresholds of significance: *italic:* $x_{0.10}$; **bold:** $x_{0.05}$; **bold:** $x_{0.01}$)

[1]Daily differences in meteorological variables	[2]Daily ratios of *Ambrosia* pollen counts (A), A > 1.00							
	a		b		c		d	
	thresholds of significance							
	0.233		*0.218*		*0.224*		*0.105*	
	0.276		**0.258**		**0.265**		**0.125**	
	0.358		**0.335**		**0.344**		**0.164**	
	weight	rank	weight	rank	weight	rank	weight	rank
Ambrosia	-0.985	–	0.794	–	-0.931	–	0.991	–
T_{mean}	0.014	7	0.176	3	0.102	5	0.096	3
T_{min}	0.031	6	0.107	5	**-0.391**	2	0.071	4
T_{max}	0.067	5	0.138	4	0.153	4	0.066	5
ΔT	0.010	8	-0.010	7	**0.454**	1	-0.042	6
I	0.083	4	-0.081	6	0.007	7	**-0.127**	1
RH	-0.165	3	0.002	8	0.061	6	*-0.117*	2
V	0.185	2	**-0.623**	1	0.215	3	-0.023	7
R	**-0.294**	1	*-0.254*	2	–	–	–	–

[1]: value on the given day – value on the day before; [2]: value on the given day per value on the day before; a: rainy day, preceded by a rainy day; b: rainy day, preceded by a non-rainy day; c: non-rainy day, preceded by a rainy day; d: non-rainy day, preceded by a non-rainy day;
T_{mean} = daily mean temperature; T_{min} = daily minimum temperature, T_{max} = daily maximum temperature, ΔT = daily temperature range; I = irradiance, RH = relative humidity; V = wind speed; R = rainfall

4. DISCUSSION

The analysis of day-to-day variations of *Ambrosia* pollen counts is an important area of pollen research, due to its immediate association with public health. Our study can be considered specific, since the subject of the paper has not been found in the international literature; hence, *Ambrosia* pollen has apparently not been studied from this point of view either. A novel procedure is applied in our study; namely, factor analysis with special transformation.

Factor analysis with special transformation was applied in order to examine the role of the meteorological variables in day-to-day variations of *Ambrosia* pollen concentrations and to determine their rank of importance in influencing daily ratios of *Ambrosia* pollen counts.

Rainfall (R) belongs to the first two most important meteorological parameters for all three data sets, except for category (b) for which $A \leq 1.00$ (Table 2). However its association with the daily ratios of *Ambrosia* pollen counts is different for categories (a) and (b). Namely, for category (a) rainfall is proportionally associated with daily pollen ratios in all three data sets (Tables 1-3). The reason of this relationship can be as follows. Due to a rainfall on the preceding day, the water balance of the taxon may improve substantially, facilitating a higher pollen release on the given day (positive effect). However a rainfall on the given day, depending on its intensity, may substantially reduce airborne pollen counts (negative effect). As a result, since summer rainfalls are generally short showers early in the afternoon, a more intensive however short rainfall may involve higher pollen counts adding a higher weight to the given-day-related pollen count increase associated with the preceding-day rainfall compared to the given-day-related decrease in pollen counts induced by the rainfall on the given day (Tables 1-3). At the same time, for category (b) in the total data set (Table 1) and in that for which $A > 1.00$ (Table 3) rainfall is in an inverse association with daily pollen ratios. This association can be explained (1) by the well-known wash-out effect: after rainfall the pollen content of the air reduces sharply (Déchamp and Penel 2002, Kasprzyk 2008, Hernández-Ceballos et al. 2011); (2) another reason of the negative association between rainfall and the pollen variable is the fact that rainfall is accompanied with a fall in temperature, which slows the metabolism of the taxon down (Deák 2010) (Table 1, Table 3). Based on the international literature, the role of rainfall is not clear in influencing daily pollen counts. Fornaciari et al. (1992) and Galán et al. (2000) found the impact of rainfall complicated just because of the negative effect of rain intensity on pollen counts. Fornaciari et al. (1992) computed the best correlation by comparing pollen concentrations (Urticaceae) and meteorological parameters on non-rainy days. For several cases *Ambrosia* pollen grains were negatively correlated with rainfall (Barnes et al. 2001, Déchamp and Penel 2002, Peternel et al. 2005, Peternel et al. 2006, Kasprzyk 2008) at the same time, Bartkova-Scevkova (2003) did not find any statistically significant association.

The importance of mean temperature (T_{mean}) is varying and its role is ambivalent for the different data sets and categories (Tables 1-3). For category (a) in the total data set (Table 1) it is in a positive, while for categories (a) and (d) in the data set for which $A \leq 1.00$ (Table 2) it is in a negative association with daily pollen ratios. These relationships can be explained as follows. In the case of adequate humidity conditions an increase in the mean temperature (T_{mean}), can accelerate vegetative and hence generative functions, if it is not too far from its optimum value. Accordingly, it involves an increase in pollen concentrations, indicating a proportional association [Table 1, category (a)] (confirmed by Bartkova-Scevkova 2003, Gioulekas et al. 2004, Kasprzyk 2008). At the same time, when there is a lack of available water, an excessive increase in mean temperature (T_{mean}) can mean a barrier for the pollination of *Ambrosia*, as the plant concentrates on preserving water and maintaining its vegetative life functions in contrast to the generative functions (Deák 2010). Hence, in this case mean temperature (T_{mean}) shows an inverse association with the daily ratios of *Ambrosia* pollen counts [Table 2, categories (a) and (d)].

Minimum temperature (T_{min}) is a relevant parameter for category (c) both in the data set for which $A \leq 1.00$ (Table 2) and for which ($A > 1.00$) (Table 3), indicating an inverse and a proportional association, respectively. The inverse relationship can be explained with the following. If the preceding day is rainy, the cooling effect of rainfall can cause a low temperature early in the morning; however, the daily pollen ratio increases, since the given-day-related pollen count increase associated with the preceding-day rainfall has a higher weight compared to the given-day-related decrease in pollen counts induced by the low minimum temperature on the given day (Table 2). The potential reason of the proportional association between these variables is that very low minimum temperatures can be a barrier of the pollen production as low temperatures make the life functions of *Ambrosia* slower (Table 3).

Maximum temperature (T_{max}) is an important variable representing a proportional association with the daily pollen ratios for category (a) in the total data set (Table 1); at the same time it is in a proportional and an inverse relationship with the resultant variable for categories (c) and (d) in the data sets for which $A \leq 1.00$ (Table 2) and for which ($A > 1.00$) (Table 3), respectively. The proportional relationship may be explained as follows. The dehiscence of anthers and release of pollen result from the dehydration of the walls of anther sacs (Kozlowski and Pallardy 2002), that is facilitated by higher maximum temperatures. Accordingly, higher values of this explanatory variable contribute to higher pollen release. At the same time this association may not be valid for a non-rainy day, preceded by a non-rainy day [category (d) in the data set for which $A \leq 1.00$; Table 2]. In summer time, extremely high maximum temperatures may indicate a limit for pollen production. In this period the loss of water can mean a barrier for the plant, so for preserving water it may decrease pollen production.

Temperature range (ΔT) is in a significant positive relationship with the daily ratios of *Ambrosia* pollen counts for category (a) in the total data set (Table 1) and for category (c) in the data set for which $A \leq 1.00$ (Table 2). At the same time, these variables show an inverse association for categories (a) and (d) in the data set for which $A \leq 1.00$ (Table 2) and for category (c) in the data set for which $A > 1.00$ (Table 3). An increase in temperature range (ΔT) may occur through a decrease in minimum temperature (T_{min}) or an increase in maximum temperature (T_{max}) or both. The reason of an inverse relationship is that very low temperatures cause a slower metabolism in the plant inducing a smaller pollen production, while in the case of extreme high temperatures the plant is forced to preserve water in its body for survival and, hence, decreases its pollen production. Accordingly, an increase in temperature range (ΔT) is inversely associated with daily ratios of *Ambrosia* pollen counts. However, if the increase in temperature range (ΔT) remains within a limit, it may show a proportional relationship with daily pollen ratios.

Irradiance (I) shows a proportional and an inverse association with daily ratios of *Ambrosia* pollen counts for category (c) in the data sets for which A ≤ 1.00 (Table 2) and for which A > 1.00 (Table 3). The proportional association is due to the fact that this variable contributes to maintaining elementary vegetative phyto-physiological processes that are important for producing pollen grains. However, the inverse association can be connected to an extremely high irradiance (I) related excessive increase in mean temperature (T_{mean}), when the plant concentrates on preserving water and maintaining its vegetative life functions and is pressed to restrict its generative functions (Deák 2010).

Relative humidity (RH) is inversely associated with daily pollen ratios for category (c) in all three data sets (Tables 1-3). In general, pollen shedding is associated with the shrinkage and rupture of anther walls by low relative humidity (Kozlowski and Pallardy 2002). Hence, relative humidity is inversely associated with pollen release (Bartkova-Scevkova 2003, Gioulekas et al. 2004). Furthermore, humid air promotes the sticking of pollen grains, which also contributes to an inverse association (affirmed by 23).

Wind speed (V) is associated with daily ratios of *Ambrosia* pollen counts inversely for category (a) in the total data set (Table 1), for category (b) in the total data set (Table 1) and in the data set for which A > 1.00 (Table 3) and for category (c) in the data sets for which A ≤ 1.00 (Table 2). At the same time, this association is proportional for categories (a), (b) and (d) in the data set for which A ≤ 1.00 (Table 2). When analysing the role of wind speed a (1) physical (Deák 2010), a (2) physiological (Deák 2010) and a (3) transport factor (Makra et al. 2010) should be considered. (1) Wind speed can hinder the sticking of pollen grains (Makra et al. 2010); at the same time, (2) a higher wind speed increases evapotranspiration leading to a loss of water in the plant and the soil. This can indirectly be a limiting factor for pollination, since the plant is forced to preserve water that is more important for its life functions than producing pollen grains (negative effect). Furthermore, (3) long-range pollen transport may also have a substantial effect on local pollen counts (Makra et al. 2010). As a proportional association, slow life functions of the taxon, related to low mean temperature in accordance with factor (2), reduce pollen production. Parallel to this, long-range transport together with its physical effect in factor (1) may have a higher weight in increasing pollen counts than the physiological factor through its decreasing effect. A positive association between wind speed and daily pollen ratios is confirmed by Gioulekas et al. (2004), Kasprzyk (2008) and Hernández-Ceballos et al. (2011). Reversely, an inverse relationship can be explained as follows. If mean temperature (T_{max}) is around its optimum for *Ambrosia*, it facilitates to produce a substantial amount of pollen. Then, wind transports the locally produced pollen and a smaller amount of pollen is transported from other sites to the local environment instead. A further possibility for an inverse association can be traced back to an extremely high mean temperature (T_{max}), which can result in a significant decrease in available water, leading to a limited pollen production. In this case, transported pollen from remote places may have a higher weight in the total pollen amount than locally produced pollen.

5. CONCLUSIONS

When using factor analysis with special transformation, for all four categories examined in the three data sets, wind speed (V), rainfall (R) and temperature range (ΔT) were the most important parameters with 7, 5 and 5 significant associations with the daily ratios of *Ambrosia* pollen counts, respectively. At the same time, minimum temperature (T_{min}) and irradiance (I) were the least important meteorological variables influencing the resultant variable. After dividing the total data set into two groups, a tendency of stronger associations between the meteorological variables and the pollen variable was found in the data set for which A ≤ 1.00 (Table 2), compared to that for which A > 1. This is due to the difference in the behaviour of the plant to stand environmental stress. Namely, the data set for which A ≤ 1.00 can be associated to lower summer temperatures with near-optimum phyto-physiological processes, while the category of A > 1.00 is involved with high and extreme high temperatures modifying life functions and, hence, the interrelationships of the meteorological and pollen variables (Tables 1-3).

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ASSOCIATION BETWEEN EXTREME DAILY POLLEN CONCENTRATIONS FOR SZEGED, HUNGARY AND PREVIOUS-DAY METEOROLOGICAL ELEMENTS

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Summary: The aim of this paper is to analyse how meteorological elements relate to extreme *Ambrosia* pollen load on the one hand and to extreme total pollen load excluding *Ambrosia* pollen on the other for Szeged, Southern Hungary. The data set comes from a 9-year period (1999-2007) and includes previous-day means of five meteorological variables and actual-day values of the two pollen variables. Factor analysis with special transformation was performed on the meteorological and pollen load data in order to find out the strength and direction of the association of the meteorological and pollen variables. Then, using selected low and high quantiles corresponding to probability distributions of *Ambrosia* pollen and the remaining pollen loads, the quantile and beyond-quantile averages of pollen loads were compared and evaluated. Finally, a nearest neighbour (NN) technique was applied to discriminate between extreme and non-extreme pollen events using meteorological elements as explaining variables. Using a nearest neighbour technique, explaining variables in decreasing order of their influence on *Ambrosia* pollen load are temperature, global solar flux, relative humidity, air pressure and wind speed, while on the load of the remaining pollen are temperature, relative humidity, global solar flux, air pressure and wind speed.

Key words: *Ambrosia*, extreme daily pollen load, meteorological elements, factor analysis including special transformation, t-test, nearest neighbour technique

1. INTRODUCTION

The connection of meteorological elements with pollen concentrations is widely studied in the literature. Finding a statistically significant association between daily pollen levels and daily meteorological elements is of great practical importance. These kinds of examinations concern all pollen types and include correlation analyses (Celenk et al. 2009, Kasprzyk and Walanus 2010), forecasting characteristics of the pollen season (García-Mozo et al. 2009, Kasprzyk 2009) and pollen concentration using regression models (Makra et al. 2004, Ocana-Peinado et al. 2008), neural and neuro-fuzzy models (Aznarte et al. 2007) or multivariate statistical methods (Makra et al. 2006, Hart et al. 2007).

However, the role of the values of meteorological elements in the occurrence of extreme daily pollen concentrations has received little attention so far. Frei (2004, 2006) studied the occurrences of extreme events (storms, floods or droughts) with extreme birch and grass pollen concentrations on the data set of Basel. The heat wave over Europe in summer 2003 with mean temperature exceeding the 1961-1990 mean by about 5°C in June, July and August substantially influenced pollen phenology and pollen production in

Switzerland (Gehrig 2006). The grass pollen season was most affected starting 1-2 weeks earlier and ending 7-33 days earlier than in general. Extremely high *Chenopodium*, *Plantago* and Poaceae daily pollen concentrations were measured in this pollen season. Cariñanos et al. (2000) analyzed the yearly distribution and severity of *Artemisia* and Chenopodiaceae-Amaranthaceae pollen load, indicating the highest and very high pollen levels in a rural area with sub-desert climate and extreme dryness.

Due to the worldwide increasing trend and ever increasing frequency of extremely high temperatures the start of flowering occurs several days earlier, furthermore a trend towards higher annual pollen quantities and an increase of the highest daily mean pollen concentrations can also be observed (Frei 2008, Frei and Gassner 2008). The recent climate change, global warming, may facilitate the extension of the habitat region of herbaceous and arboreal plants contributing to the increase of pollen levels and an exacerbation of their adverse effects, hence to the rise of pollen sensitivity and respiratory admissions due to a pollen allergy.

The purpose of this paper is to analyse how meteorological elements relate to extreme *Ambrosia* pollen load on one hand and to extreme total pollen load excluding *Ambrosia* pollen on the other. For this aim, a factor analysis with special transformation was performed on the meteorological and pollen load data in order to find out the strength and direction of the association of the meteorological and pollen variables. Then, using selected low and high quantiles corresponding to probability distributions of *Ambrosia* pollen and the remaining pollen loads the quantile and beyond-quantile averages of pollen loads were compared and evaluated. Finally, a nearest neighbour (NN) technique was applied to discriminate between extreme and non-extreme pollen events using meteorological elements as explaining variables.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N; 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the rivers Tisza and Maros (Fig. 1). The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m AMSL. The city is the centre of the Szeged region with 203,000 inhabitants. The climate of Szeged belongs to Köppen's *Ca* type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931). The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged some 20 m above the ground surface (Fig. 1) (Makra et al. 2008).

In order to determine the association between meteorological variables on one hand and *Ambrosia* pollen load as well as the total pollen load excluding *Ambrosia* pollen on the other, previous-day values of five meteorological variables (mean temperature, mean global solar flux, mean relative humidity, mean sea-level pressure and mean wind speed) and actual-day values of the two pollen variables were considered. A slight refinement of the methodology could involve not only previous-day meteorological variables as influencing variables but their two (or more) days earlier values as well. However, it was found that earlier-days meteorological parameters deliver negligible further information on the actual-day pollen concentration (Makra and Matyasovszky 2011).

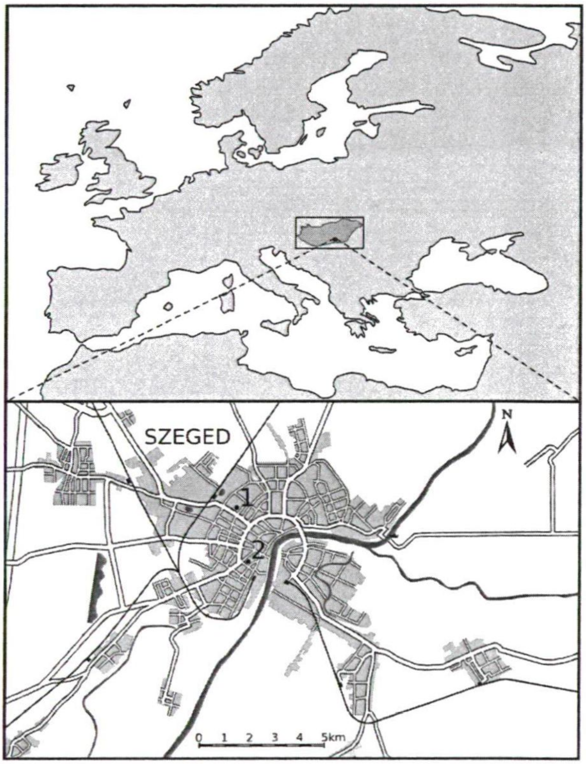

Fig. 1 Location of Europe including Hungary (upper panel) and the urban web of Szeged with the positions of the data sources (lower panel). 1: meteorological station; 2: aerobiological station. The distance between the aerobiological and the meteorological station is 2 km.

Meteorological data were collected in the monitoring station (operated by the Environmental and Natural Protection and Water Conservancy Inspectorate of Lower-Tisza Region, Szeged) located in the downtown of Szeged at a distance of about 10 m from the busiest main road.

Besides the pollen of *Ambrosia* (ragweed), the pollen production of 23 other relevant taxa are taken into account. The taxa considered, with their Latin (English) names are as follows: *Acer* (maple), *Alnus* (alder), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), *Carpinus* (hornbeam), Chenopodiaceae (goosefoots), *Corylus* (hazel), *Fraxinus* (ash), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (plane), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Salix* (willow), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle).

The analysis was performed for the nine-year period 1999-2007 with two data sets according to the pollen season of *Ambrosia* (ragweed) (July 15 – October 16) and the pollen season of remaining pollen excluding that of *Ambrosia* (January 14 – October 16).

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain m^{-3} of air is recorded and at least

5 consecutive (preceding) days also show 1 or more pollen grains m^{-3} (Galán et al. 2001). The pollen season varies from year to year; here the longest observed pollen season during the nine-year period was considered for each year.

Note that we define pollen load as a number indicating to what extent the body is endangered by the pollens. When calculating pollen load, the allergenic effects of all actually blooming herbaceous and arboreal plants are considered. According to the degree of allergenicity pollen types can be sorted into four categories: 1) weakly, 2) moderately, 3) intensely and 4) severely allergenic pollen types. For example, the allergenicity of *Ambrosia* is severe indicated by the scale value 4, while that of *Juglans* is weak denoted by the value 1. Hence, pollen load is the sum of the pollen concentrations multiplied by their degrees of allergenicity (www.pollenindex.hu/).

2.2. Methods

2.2.1. Factor analysis with special transformation

Factor analysis identifies linear relationships among subsets of examined variables and this helps to reduce the dimensionality of the initial database without substantial loss of information. First, a factor analysis was applied to the initial dataset consisting of 5 meteorological parameters as explaining variables on one hand and *Ambrosia* pollen load and that of the remaining pollen on the other. The procedure was performed for the two pollen variables as resultant variables separately in order to transform the original variables to fewer variables. These new variables (called factors) can be viewed as latent variables explaining the joint behaviour of weather-pollen variables. The optimum number of retained factors is determined by different statistical criteria (Jolliffe 1993). The most common and widely accepted method is to specify a least percentage (80%) of the total variance in the original variables that has to be achieved (Liu 2009). After performing the factor analysis, a special transformation of the retained factors was made to discover to what degree the above-mentioned explaining variables affect the resultant variable, and to give a rank and sign of their influence (Jahn and Vahle 1968).

2.2.2. t-test

Quantiles corresponding to probabilities 10%, 20% and 30%, furthermore 90%, 80% and 70% were determined first. Note that a *p*-quantile ($0<p<100\%$) q_p is the value below which the pollen load occurs with relative frequency *p*. The pollen loads were then assigned to two categories according to whether the actual pollen load is below or not the actual quantile. Values of daily meteorological variables corresponding to the next-day pollen load below its quantiles 10%, 20% and 30% and above the quantiles 90%, 80% and 70% were analysed. The *t*-test (Zimmerman 1997) was used to decide whether pollen category related means of each meteorological variable differ significantly under each quantile both for *Ambrosia* pollen and the remaining pollen.

2.2.3. Nearest neighbour (NN) technique

An NN technique was developed and applied in order to decide which of the two categories of the next-day pollen load occurs under actual values of the 5 meteorological variables. A nearest neighbour of the actual daily meteorological variables is identified with the day where the explaining variables are the most similar to the actual explaining variables. Then the decision on the pollen load category for this case is the category being present on the selected day.

The procedure was used for every day available. The similarity is measured with the Euclidean distance defined with the standardised explaining variables. Standardization is necessary to ensure the same magnitude of each explaining variable and thus to ensure their equal importance. It was performed for every explaining variable separately by dividing the difference between the data and their mean by the standard deviation. Due to the annual trends in both the pollen loads and the meteorological variables a time window h was defined around each actual day and the nearest neighbours were searched within the time period defined by this window. Additionally, not only the unique nearest neighbour but the first k nearest neighbours were selected and the final decision on the category was defined as the majority decision of the k number individual decisions. Parameters h and k were determined from the first eight years (learning set) as to provide a best ratio of good decisions to all decisions, and the procedure was verified using the data of the last year.

3. RESULTS AND DISCUSSION

3.1. Factor analysis with special transformation and t-test

After performing a factor analysis (altogether 2 factor analyses), 4 factors were retained both for the pollen season of *Ambrosia* and the pollen season of remaining pollen excluding that of *Ambrosia*. In order to calculate the rank of importance of the explaining variables (meteorological parameters) in determining the resultant variable (pollen variables), loadings of the retained factors were projected onto Factor 1 (with a special transformation) (Tables 1a-b) (Jahn and Vahle 1968).

Table 1a Special transformation. Effect of the explanatory variables on *Ambrosia* pollen load and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable (thresholds of significance: *italic:* $x_{0.05} = 0.068$; **bold:** $x_{0.01} = 0.090$)

Variables	weight	rank
Ambrosia (pollen·m^{-3}·day^{-1})	1.000	–
Temperature (°C)	**0.153**	1
Global solar flux (W·m^{-2})	**0.136**	3
Relative humidity (%)	**-0.110**	4
Air pressure (hPa)	**-0.143**	2
Wind speed (m·s^{-1})	0.045	5

It is found that except for wind speed, the remaining four meteorological variables display significant associations with the *Ambrosia* pollen load. Temperature and global solar flux show proportional, while air pressure and relative humidity inversely proportional associations with *Ambrosia* pollen loads. Explaining variables in decreasing order of their influence on *Ambrosia* pollen load are temperature, air pressure, global solar flux, relative humidity and wind speed (Table 1a).

The remaining pollen load excluding that of *Ambrosia* shows notable association with all five meteorological variables (Table 1b). The signs of the connections between the meteorological parameters and the remaining pollen are the same as they are between the meteorological parameters and the *Ambrosia* pollen (Tables 1a-b). The meteorological variables thus affect the two pollen variables similarly despite the different pollen seasons. Explaining variables in decreasing order of their influence are relative humidity, global solar flux, temperature, wind speed and air pressure. The importance of the individual meteorological parameters based on their factor loadings differ in determining the two pollen variables due to their different phenological characteristics including different length of pollen seasons and different climate requirements (Tables 1a-b).

Table 1b Special transformation. Effect of the explanatory variables on total pollen load excluding *Ambrosia* pollen and the rank of importance of the explanatory variables on their factor loadings transformed to Factor 1 for determining the resultant variable(thresholds of significance: *italic:* $x_{0.05} = 0.041$; **bold:** $x_{0.01} = 0.054$)

Variables	weight	rank
Total pollen excluding *Ambrosia* (pollen$\cdot$m$^{-3}\cdot$day^{-1})	1.000	–
Temperature (°C)	**0.188**	3
Global solar flux (W$\cdot$m^{-2})	**0.237**	2
Relative humidity (%)	**-0.276**	1
Air pressure (hPa)	**-0.068**	5
Wind speed (m$\cdot$s^{-1})	**0.121**	4

Table 2 Significance levels for differences between means of meteorological variables corresponding to below and above the *p* quantiles of pollen loads. Symbols x, xx, xxx and xxxx refer to the 10%, 5%, 1% and 0.1% probability levels, respectively. T - temperature, G - global solar flux, RH - relative humidity, P - air pressure, W - wind speed

	Ambrosia						Total pollen excluding *Ambrosia*					
p	90% q_{90}=1016	80% q_{80}=552	70% q_{70}=348	10% q_{10}=4	20% q_{20}=12	30% q_{30}=28	90% q_{90}=333	80% q_{80}=245	70% q_{70}=188	14.65% $q_{14.65}$=1	20% q_{20}=17	30% q_{30}=50
T	xx	xxx	xxxx	xxx	x	xx		xxxx	xxxx	xxxx	xxxx	xxxx
G	xxx	xxxx	xxxx	x			xx	xxxx	xxxx	xxxx	xxxx	xxxx
RH		xxx	xxxx		x	xx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
P	xxxx	xx	xxx	xxxx	xxxx	xxxx	x	xxx	xxx	xxx	xxx	xxx
W				xx			xxx	xxxx	xxxx	xxxx	xxxx	xxxx

The *t*-test shows rather significant differences between the means of meteorological variables corresponding to below and above the quantiles of pollen loads excluding *Ambrosia* (Table 2) potentially due to the annual trends in both the meteorological elements and the pollen load. Here 14.65% is used instead of 10% as the relative frequency of zero loads is 14.65%. However, similar differences are less significant for the load of *Ambrosia* pollen mainly for wind speed and partially for low quantiles (Table 2). This may partly be due to the fact that annual trends are not so characteristic during the relatively short pollen season of *Ambrosia*. One may suspect, therefore, that these highly significant differences are found only due to the annual cycles inherent in both the meteorological variables and pollen concentrations.

3.2. NN technique

In order to clarify whether the 5 meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events an NN technique outlined in Section 2.2.3 was applied. The optimal time window *h* is 3 days and 5 days for *Ambrosia* pollen load and total pollen load excluding *Ambrosia* pollen, respectively. The choice of such a small window for *Ambrosia* pollen is reasonable because the pollen load varies in a very wide range (from 0 to 5540 in the 8 years) during a relatively short pollen season. In contrast, the load of the remaining pollen varies in a narrower range (from 0 to 3020 in the 8 years) during a three times longer period. The optimal number k of nearest neighbours is 7 for *Ambrosia* pollen and 5 for the remaining of pollen, respectively. The larger value of k for *Ambrosia* seems to balance the narrower time window. Values of h and k were determined as to minimise the number of false decisions only for events exceeding or not exceeding the quantiles corresponding to $p_M = \max\{p, 1-p\}$ or $p_m = \min\{p, 1-p\}$, respectively, as there is a tendency to underestimate these events and overestimate the complementary events.

Table 3 Contingency table for above and below the quantiles of *Ambrosia* pollen load. Values in rows/columns include the observed/estimated number of cases.

Set	Quantile							
	80%		70%		20%		30%	
Learning	Above	Below	Above	Below	Above	Below	Above	Below
Above	112	33	189	28	570	34	495	27
Below	42	543	38	475	35	91	35	173
Verification	Above	Below	Above	Below	Above	Below	Above	Below
Above	14	5	24	4	74	4	64	3
Below	5	70	5	61	5	11	5	22

Table 4 Contingency table for above and below the quantiles of the total pollen load except for *Ambrosia* pollen. Values in rows/columns include the observed/estimated number of cases.

Set	Quantile							
	80%		70%		20%		30%	
Learning	Above	Below	Above	Below	Above	Below	Above	Below
Above	216	181	408	190	1528	75	1345	56
Below	193	1412	178	1226	61	338	78	523
Verification	Above	Below	Above	Below	Above	Below	Above	Below
Above	26	22	49	23	184	8	161	7
Below	22	170	22	146	8	40	9	63

Tables 3 and 4 compare the observed below or above quantile events to events obtained from NN decisions. Quantiles p=10% and 90% are not included here because the number of events exceeding the quantile of 90% and not exceeding that of 10% is strongly underestimated even with the optimal time window and the number of nearest neighbours. The percentage of good decisions is slightly over 30% for this case, while the similar percentage for complementary events (not exceeding the quantile of 90% and exceeding that of 10%) is around 97-99%. The procedure, however, works quite well for quantiles of 20% and 80%, and even better for those of 30% and 70%. The question is whether pollen loads corresponding to their quantiles of 20-30% and 70-80% can be labelled extremes. The answer is yes when taking into account the clinical threshold of pollen load. Specifically, the clinical threshold for *Ambrosia* pollen concentration is 30 pollen grains m^{-3} in Hungary (Makra et al. 2005) corresponding to a pollen load of 120 considering its severe allergenicity, but for other countries this threshold is only 10 or even just a mere 5 pollen grains m^{-3} (Banken and Comtois 1992) corresponding to pollen loads of 40 and 20, respectively. Thus, the quantiles of 30% (see Table 2) are around the clinical thresholds of pollen loads and characterise a lower limit of the pollen load that would be be critical for sensitive people. In contrast, the quantiles of 80% accompanied with pollen loads 552 and 245 for *Ambrosia* and the remaining of pollen (Table 2) respectively are well above the clinical threshold of pollen load and hence these values indicate serious adverse effects for those being sensitive to respiratory ailments.

The relative frequency of the number of decisions for exceeding the quantiles of 80%, 70%, 20% and 30% is 21.1%, 31.1%, 82.2% and 72.6% respectively in the learning set, and 20.2%, 30.1%, 84% and 73.4% respectively in the test set for *Ambrosia*. Similar relative frequencies for the remaining pollen are 20.4%, 29.3%, 79.4% and 71.1% for the learning set and 20.4%, 29.6%, 80.0% and 70.8% for the test set, respectively. These numbers show that the NN procedure avoids substantial under- or overestimation of event frequencies defined by the above quantiles. For the test set, the relative frequency of good decisions for exceeding the quantiles of 80%, 70%, 20%, 30% is 73.7%, 85.7%, 94.9% and 95.5%, while for not exceeding these quantiles is 93.3%, 92.4%, 68.8% and 81.5% for *Ambrosia*. Similar values for total pollen excluding *Ambrosia* are 64.2%, 68.1%, 95.8% and 95.8%, as well as 88.5%, 86.9%, 83.3% and 87.5%. These percentages show that the five meteorological elements as explaining variables are informative to discriminate between extreme and non-extreme pollen events.

Explaining variables in decreasing order of their influence on *Ambrosia* pollen load are temperature, global solar flux, relative humidity, air pressure and wind speed, while on the load of the remaining pollen these are temperature, relative humidity, global solar flux, air pressure and wind speed. These orders were determined with the help of the numbers of good decisions for events of exceeding or not exceeding the quantiles corresponding to p_M or p_m when neglecting different explaining variables from all of the five variables. Note that the rank of importance of the meteorological elements determining the two pollen variables partly differ from the above orders when using factor analysis with special transformation. Its reason is that factor analysis explores linear relationships among variables coming from two sources. Namely, the relationship between two variables is partly due to the similarity (or dissimilarity) of their annual cycles but partly due to the correlation between variations around these annual cycles. Hence, factor analysis shows an overall picture, while the NN technique reflects the relationship between the daily variations of explaining variables and pollen loads excluding the annual cycles when using time windows. Additionally, the application of the NN procedure allows a non-linear relationship between explaining variables and pollen loads.

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CLIMATE SENSITIVITY ANALYSIS OF ALLERGENIC TAXA IN CENTRAL EUROPE WITH NEW ECOLOGICAL INDICATORS

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Summary: The aim of the study is to analyse trends of the pollination season with its duration, start and end dates, as well as trends of the annual total pollen count and annual peak pollen concentration for the Szeged agglomeration in Southern Hungary. The data set covers an 11-year period (1997-2007) including 19 taxa and seven daily climate variables. Trend analysis is performed on both annual and daily bases. Trend analysis on daily bases is a new approach providing information on the annual cycles of trends. For quantifying the strength of the relationship between the annual cycle of the slope of daily trends of the pollen concentrations and the annual cycles of slopes of daily trends of the climate variables an association measure and a multiple association measure are introduced. Individual taxa are sorted into three categories according to their climate sensitivities. These are compared with two novel climate change related indicators, namely risk potential and expansion potential due to the climate change. A novel procedure was applied to separate the effect of the past and current weather conditions in influencing current *Ambrosia* pollen concentration. The potential effect of land use changes on the pollen release of the taxa considered is also discussed using CORINE Land Cover Database.

Key words: pollen, pollen season, trend, ecological indicator, climate change, respiratory allergy

1. INTRODUCTION

Recently, the Earth's ecosystem is experiencing a global warming. Climate change is responsible for the observed northward and uphill distribution shifts of many European plant species. By the late 21st century, distributions of European plant species are projected to have shifted several hundred kilometres to the north (Emanuel et al. 1985, Pearson 2006, Parry et al. 2007, Lindner et al. 2010); forests are likely to have contracted in the south (Penuelas and Boada 2003) and expanded in the north (Leemans et al. 1996, Pearson 2006, Lindner et al. 2010). The rate of change will exceed the ability of many species to adapt. Concerning plant phenology, the timing of seasonal events in plants is changing across Europe due to changes in climate conditions. Between 1971 and 2000, the average advance of spring and summer was 2.5 days per decade. The pollen season starts on average 10 days earlier and is longer than 50 years ago (Feehan et al. 2009).

A recent warming is associated with an earlier onset (Frei 2008, Rodríguez-Rajo et al. 2011), an earlier end date (Stach et al. 2007, Recio et al. 2010), a longer pollen season (Stach et al. 2007, Ariano et al. 2010), an increase in the total annual pollen load (Ariano et al. 2010, Cristofori et al. 2010), furthermore an increase of patient number sensitized to pollen throughout the year (Ariano et al. 2010).

The scope of the studies is generally limited to only one taxon (Peternel et al. 2006, Alcázar et al. 2011), or a very small number of taxa (García-Mozo et al. 2010, Kaminski and Glod 2011, Rodríguez-Rajo et al. 2011). A comprehensive spectrum of the regional pollen flora was only analysed in three studies, namely in Clot (2003, 25 plant taxa), Damialis et al. (2007, 16 plant taxa) and Cristofori et al. (2010, 63 plant taxa). An overall analysis of the pollen season characteristics for a given source area provides a more reliable picture of the climate sensitivity for each taxon studied based on their different optimum environmental conditions.

Precognition of pollen season characteristics is important for those people suffering from pollen-induced respiratory diseases, who can prepare in due time for days of extreme high pollen load. At the same time, climate change can affect pollen characteristics of different taxa diversely. The object of this paper is to study an extended spectrum of airborne pollen characteristics (19 plant taxa) for the Szeged region in Southern Hungary. Trends of both quantity-related and phenological pollen season characteristics are calculated for each taxon. A multiple association measure (MAM) is introduced that describes how well the annual cycle of daily pollen concentration trends can be represented by a linear combination of annual cycles of climate variable trends. Two novel climate change related indicators, namely risk potential (RP) and expansion potential (EP) due to the climate change are also introduced and these indicators are evaluated for each taxon. Additionally, a novel procedure was applied to separate the effect of the past and current weather conditions in influencing current *Ambrosia* pollen concentration. The potential effect of land use change on *Ambrosia* pollen concentration is also discussed using CORINE Land Cover Database.

2. MATERIALS AND METHODS

2.1. Location and data

Szeged (46.25°N; 20.10°E), the largest settlement in South-eastern Hungary is located at the confluence of the Rivers Tisza and Maros. The area is characterised by an extensive flat landscape of the Great Hungarian Plain with an elevation of 79 m above sea level. The city is the centre of the Szeged region with 203,000 inhabitants. The climate of Szeged belongs to Köppen's *Ca* type (warm temperate climate) with relatively mild and short winters and hot summers (Köppen 1931).

The pollen content of the air was measured using a 7-day recording "Hirst-type" volumetric trap (Hirst 1952). The air sampler is located on top of the building of the Faculty of Arts at the University of Szeged approximately 20 m above the ground surface (Makra et al. 2010). Meteorological variables include daily values of minimum (T_{min}, °C), maximum (T_{max}, °C) and mean temperature (T, °C), total solar radiation (TR, $W \cdot m^{-2}$), relative humidity (RH, %), wind speed (WS, $m \cdot s^{-1}$) and rainfall (R, mm). They were recorded in a meteorological station located in the inner city area of Szeged. The data set consists of daily pollen counts (per m^3 of air) of 19 taxa taken over the period 1997-2007. With their Latin (English) names they are: *Alnus* (alder), *Ambrosia* (ragweed), *Artemisia* (mugwort), *Betula* (birch), *Cannabis* (hemp), Chenopodiaceae (goosefoots), *Juglans* (walnut), *Morus* (mulberry), *Pinus* (pine), *Plantago* (plantain), *Platanus* (plane), Poaceae (grasses), *Populus* (poplar), *Quercus* (oak), *Rumex* (dock), *Taxus* (yew), *Tilia* (linden), *Ulmus* (elm) and *Urtica* (nettle). The 19 taxa studied produce 93.2% of the total pollen amount for the given period. Taxa with the highest pollen levels include *Ambrosia* (32.3%), Poaceae (10.5%), *Populus* (9.6%) and *Urtica* (9.1%), which together account for 61.5% of the total pollen production.

As regards the taxa with the highest pollen concentrations, the *Ambrosia* genus has only one species, namely *Ambrosia artemisiifolia* (Common Ragweed) in the Szeged region that appears both in the urban environment and in the countryside. Ragweed occurs especially frequently west of the city. The ruling north-western winds can easily transport pollen into the city. Since in the sandy region, northwest of Szeged, stubble stripping is not necessary for ground-clearance due to the mechanical properties of sandy soils, *Ambrosia* can spread unchecked. Owing to newly-built motorways around Szeged, several farmland areas have been left untouched for a long time that also favour the expansion of *Ambrosia*. Several species of the Poaceae family occur in the Szeged area, namely *Agropyron repens* (Common Couch), *Poa trivialis* (Rough Meadow-grass), as well as *Poa bulbosa* (Bulbous Meadow-grass) over untouched areas, furthermore *Poa angustifolia* (Narrow-leaved Meadow-grass) and *Alopecurus pratensis* (Meadow Foxtail) in the floodplain, and along the dyke surrounding Szeged. Along the urban lakesides *Phragmites australis* (Common Reed) is the most frequent Poaceae. Furthermore, on short grass steppes of sand, loess and saline areas *Festuca pseudovina* and *Festuca rupicola* also occur. For *Populus* genus, natural species of *Populus alba* (White Poplar) and *Populus canescens* (Grey Poplar) are the most frequent in the city and are characteristic in the floodplain forests along the Tisza and Maros Rivers. In addition, cultivated poplars such as I-273 Poplar and *Populus x euroamericana* (Canadian Poplar) and its variants are frequently planted in urban parklands, public places, as well as along roads in peripheries. At the same time, the *Urtica* genus with its only species of *Urtica dioica* (Common Nettle) has a high frequency in the floodplain forest underwood of the Tisza and Maros Rivers, road-, and channel-sides and in locust-tree plantations around the city. *Urtica* also occurs in the neglected grassy areas of the city.

The remaining species are rare. *Alnus* species are only found in the Botanical Garden of Szeged. The pollen of *Artemisia, Cannabis,* Chenopodiaceae and *Rumex* can come from neglected areas of both the city and its surroundings, as well as from stubble pastures. *Betula, Juglans, Pinus, Platanus, Taxus* and *Tilia* species have been planted exclusively in public places and gardens; they have no natural habitats in the Szeged region. However, since the 1960s *Pinus* (*Pinus sylvestris* and *Pinus nigra*) species have been extensively planted in the sandy regions north-west of Szeged within the framework of an afforestation programme. Their pollen can easily reach Szeged via the north-western winds. *Morus* is planted along avenues and in public places. *Plantago* species occur in natural grassy areas of both the city and its surroundings. *Quercus* species are planted along the embankment surrounding the city, as well as north of the city. *Ulmus* is planted in the city too; however it is not very common. At the same time, *Ulmus minor* is quite frequent in all landscape types around Szeged on boundaries, road-sides and channel-sides. Its scattered monodominant plantations can appear in loess landscapes and beyond the dykes (saved-side) floodplains, as well as rarely in sand landscapes. In the above-mentioned places the formerly planted *Ulmus pumila,* as an adventive species, also occurs, but its spread is not characteristic. Large natural stands of *Ulmus minor* together with *Ulmus laevis* live in the oak-elm-ash alluvial forests alongside the River Maros, where both planted and spontaneous stands appear. These species can be found spontaneously even in the willow-poplar alluvial forests, thanks to the mature stands of the Pécska forest on the Romanian side (Deák 2010).

The pollen season is defined by its start and end dates. For the start (end) of the season we used the first (last) date on which 1 pollen grain m^{-3} of air is recorded and at least 5 consecutive (preceding) days also show 1 or more pollen grains m^{-3} (Galán et al. 2001). For a given pollen type, the longest pollen season during the 11-year period was considered for each year.

2.2. Methods

2.2.1. Trend analysis

A common way of estimating trends in data is linear trend analysis. The existence of trends is examined generally by the *t*-test based on the estimated slopes and their variances. This test, however, may only be used for normally distributed data. Data having probability distributions far from the normal one can be tested against monotone trends by the Mann-Kendall (MK) test (Önöz and Bayazit 2003). Therefore, this method is used here, although the slopes have also been calculated.

It may happen that some trends might have overly complex forms to be well approximated by global linear fits, so nonparametric methods are preferable. Nonparametric methods assume some smoothness of the trends to be estimated. Each version of these techniques results in linear combinations of observations lying within an interval around the points where the trends are estimated. The size of this interval is controlled by a parameter called the bandwidth. There are several versions of such estimators, but local linear fittings have useful properties (Fan 1993). When estimating the trends, the choice of the bandwidths has a crucial role in the overall accuracy. A large bandwidth provides small variances with large biases of the estimates, while a small bandwidth results in large variances with small biases. Thus, an optimal bandwidth producing relatively small variances and small biases has to be found. A technique proposed by Francisco-Fernández and Vilar-Fernández (2004) is used here for the purpose. Note that the local linear fits become globally linear with infinite bandwidths.

2.2.2. Taxon-specific ecological indicators as a basis for introducing new climate change related indicators

In order to evaluate the response of plants to climate change, two indicators were introduced: risk potential due to the climate change (RP) and expansion potential due to the climate change (EP). RP describes the endangerment of the species of different taxa in their present habitats indicating survival potential on their present places. EP shows the capability of the species to move in the landscape, so this term measures the landscape-scale rescue effect. Both indicators were determined for a specific taxonomic group (genus, family) of the most allergenic plants. The species-pool of the Hungarian vegetation was collected according to the Flora Database of Hungary (Horváth et al. 1995). The above-mentioned two new terms were determined on the basis of four main ecological indicators of the taxa examined. The selected indicators were: temperature requirement due to Zólyomi (TZ-value) (Zólyomi and Précsényi 1964), temperature requirement due to Soó (TS-value) (Soó 1964-1980), heat supply of species interpreted with the climate of the vegetation belts due to Borhidi (TB-value) (Borhidi 1995), as well as the degree of continentality and climate extremity tolerance according to the distribution of species due to Borhidi (CB-value) (Borhidi 1995). Substitution of species within a taxon and habitat shifts were also considered using the Hungarian National Flora Database (Horváth et al. 1995) and field knowledge (Deák 2010) detecting the effect of different climate extremities on the vegetation (Deák 2011a) (Table 1). In order to calculate the new climate change related indicators, besides the above-mentioned ecological indicators, local effects of the prospective changes predicted by recent climate models were also considered. These models count with a 2-4°C increase in annual mean temperature, lower rainfall total in the summer season, annual precipitation decreasing by 150-200 mm and a more extreme rainfall distribution throughout the year for a 100-year time scale until the end of the century (Láng et al. 2007, Czúcz 2009, Faragó et al. 2010).

Table 1 The values of the ecological indicators and the climate change related indicators for the most common allergenic taxa for Hungary

Taxa	[2]TZ-value	[3]TS-value	[4]TB-value	[5]CB-value	Risk potential due to climate change (RP)	Expansion potential due to climate change (EP)
Alnus	2, 3, 6	1, 2	3, 4, 5	4	***	-2
[1]*Ambrosia*	**0**	**0**	**8**	**6**	*	**2**
Artemisia	5, 6, 7,	2, 3, 4, 5	6, 7, 8, 9	5, 6, 7, 8, 9	*	2
Betula	3	1, 2	3, 4	3, 4	***	-2
Cannabis	5	0	7	7	*	0
Chenopodiaceae	0, 5, 6, 7	0, 2, 3, 4, 5	5, 6, 7, 8, 9	0, 2, 3, 4, 5, 6, 7, 8, 9	* **(few taxa)	1
Juglans	5	4	8	2, 5	*	2
Morus	–	–	7	5	**	-1
Pinus	3	1, 2, 4	4, 8	4, 7	**	-1
Plantago	5, 6, 7	0, 2, 3, 4	5, 6, 7, 8	0, 1, 3, 6, 7, 8	* **(few taxa)	1
Platanus	5, 6, 7	4	6, 7, 8, 9	6	*	2
[1]Poaceae	**0, 3, 4, 5, 6, 7**	**0, 2, 3, 4, 5**	**3, 4, 5, 6, 7, 8, 9**	**2, 3, 4, 5, 6, 7, 8, 9**	* **(few taxa) ***(few taxa)	**1**
[1]*Populus*	**3, 5**	**3, 4**	**5, 7, 8**	**5, 6, 7**	* **(few taxa)	**1**
Quercus	5, 6	3, 4	6, 7, 8	4, 5, 6, 7	* **(few taxa)	1
Rumex	0, 5	0, 2, 3, 4	4, 5, 6, 7, 8	2, 3, 5, 6, 7, 8	* **(few taxa)	1
Taxus	5	2	5	2	***	-2
Tilia	5, 6	3, 4	5, 7	2, 4, 7	* **(few taxa)	1
Ulmus	5	2, 3, 4	5, 6, 7	3, 5, 6	* **(few taxa)	1
[1]*Urtica*	**5, 6**	**0, 4**	**6, 7**	**4, 6**	* **(few taxa)	**1**

[1]**Bold:** taxa with the highest pollen levels;

[2]**TZ-value: temperature requirement due to Zólyomi (Zólyomi and Précsényi 1964, Horváth et al. 1995):**
–: no value is determined; 0: not characteristic; 2: in accordance with woody tundra belt; 3: in accordance with taiga belt; 4: in accordance with broad-leaved/needle-leaved mixed forest belt; 5: in accordance with broad-leaved forest belt; 6: in accordance with sub-Mediterranean forest belt; 7: in accordance with Mediterranean, Atlantic evergreen belt; (Taxa with TZ-value of 1 does not occur.)

[3]**TS-value: temperature requirement due to Soó (Soó 1964-1980, Horváth et al. 1995):**
–: no value is determined; 0: indifferent species to temperature; 1: highly cold-tolerant, arctic or alpine species; 2: cold-tolerant species; 3: slightly cold-tolerant species; 4: cold-sensitive, warm-needed species; 5: highly warm-needed species

[4]**TB-value: heat supply of species interpreted with the climate of the vegetation belts due to Borhidi (Borhidi 1995, Horváth et al. 1995):**
3: in accordance with sub-alpine or sub-boreal belt; 4: in accordance with montane needle-leaved forests or tajga belt; 5: in accordance with montane broad-leaved forest belt; 6: in accordance with sub-montane broad-leaved forest belt; 7: in accordance with thermophilous forest belt; 8: in accordance with the belts of sub-Mediterranean woodlands and continental steppes; 9: in accordance with Mediterranean evergreen belt; (Taxa with TB-values of 0, 1 and 2 do not occur.)

[5]**CB-value: degree of continentality and climate extremity tolerance in association to the distribution of species due to Borhidi (Borhidi 1995, Horváth et al. 1995):**
0: indifferent species; 1: eu-oceanic species (Atlantic species occurring just exceptionally on continental climate); 2: oceanic species (living mainly in Western-Europe and Western-Central Europe); 3: oceanic-sub-oceanic species (distribution focus on Central Europe); 4: sub-oceanic species (distribution focus on Central Europe, but rarely expanding to East); 5: sub-oceanic - sub-continental intermediate species; 6: sub-continental species (distribution focus on Eastern Central Europe); 7: continental-sub-continental species (distribution focus on Eastern Europe, but occurring in Central Europe, as well); 8: continental species (distribution focus on Eastern Europe reaching only Eastern Central Europe); 9: eu-continental species (Eastern European and Asian steppe species occurring just exceptionally in Central Europe)

2.2.3. Risk potential (RP) and expansion potential (EP) as new indicators due to climate change

RP describes the endangerment of the species of different taxa in their present habitats indicating survival potential of the species with 3 categories. Non-endangered taxa (*) can survive climate change since they contain species for warmer and drier conditions, whereas the climatically endangered taxa (***) have no species in the present flora for future changed conditions. In the first case, change of species within a taxon in a certain landscape could help the adaptation of the taxon to global warming, whereas in the latter case the lack of heat tolerant species can lead to the disappearance of a given taxon. The wider tolerance range (the more ecological indicator values, i.e. TZ-, TS-, TB-, or CB-values) (Table 1) and the more species (especially heat and drought tolerant species) a taxon has, the less exposure to climate change it has. Moderately endangered taxa (**) could survive partly in their places, but populations of some species may decrease regionally.

Three variables must be considered for a given taxon: (1) the number of species within a taxon, (2) the value range of the ecological indicators of the species within a taxon and (3) the number of heat and drought tolerant species within a taxon (this is the most important factor). For example, grasses (Poaceae) have a lot of species [see: (1)] with a wide value range of the ecological indicators of their species [see: (2)], and many of them are heat tolerant [see: (3)], so they will have enough species to adapt to the changes. However, the answers of species can be different to the climate change (all three categories of RP can occur for Poaceae) (Table 1). If a taxon contains mainly warm- and drought tolerant species (e.g. *Ambrosia, Juglans* and *Platanus*) less species need adaptation, so they are less endangered taxa. If a taxon has only a few species and neither of them favours warmer and drier conditions the chance for its extinction is significantly high (***) (e.g. *Betula* and *Alnus*) (Table 1).

EP shows the capability of the species to move in the landscape thus characterizing the rescue effect. If a taxon belongs to several categories of RP, these categories can be grouped into different classes on the basis of field experiments (Horváth et al. 1995, Deák 2010, 2011b, Bölöni et al. 2011). This feature is described with 5 classes as a wide range of responses are expected due to the different climate-tolerance of the species-pool of taxa. These classes are as follows. (0): Taxa not influenced by global warming. They could survive and their distribution area will remain about the same. (+1): Taxa not influenced by global warming, but for some species area-increase and for some others area-decrease is possible. They can survive the changes through moving in the landscape, but their expansion is limited. (+2): Taxa significantly influenced by global warming. For some species area-increase is expected. They show the best adaptation to the climate change as they will not just survive but can spread well in the landscape. For example, potential spread of species with (*) (e.g. *Ambrosia, Juglans* and *Platanus*) is expected in the landscape, so +2 value is given for them showing that their significant area increase is expected as a response for the awaited climate change. (-1): For some species regional area-decrease is possible. They can survive in a few places, their spread in the landscape is limited and area-decrease is expected. (-2): Taxa significantly influenced by global warming. For the majority of species area-decrease is expected. They have the smallest adaptation capability; they will gradually disappear and even the rescue effect in some refuges is doubtful (Table 1). For instance, *Betula* and *Alnus* are endangered taxa indicated with (***) in the RP system, so their EP value is the lowest meaning that area-decrease is expected as a result of climate change. These five categories can be useful not only to evaluate the future distribution of allergenic species groups, but they can also help to reveal the possible changes in endangered plant groups and invasive species (nature conservation aspect), as well as the spread of weeds (agricultural aspect).

On the whole, RP concentrates on the local survival specifying what will happen with the species in their present habitats, while EP concentrates on the landscape-level response. The scale of the two indicators is thus different. Note that this work is the first attempt to reveal the climate sensitivity of the main species groups of vegetation since the database applied has not been available before and sufficient field-knowledge has now been collected by several botanists.

2.2.4. Multiple association measure (MAM) and its association with RP and EP

We examined whether there were any associations between the annual cycles of daily slopes of pollen concentration trends and the annual cycles of daily slopes of climate variables trends. Here an association measure (AM) is used to characterize these relationships by calculating the correlations between the annual cycles of slopes obtained by the nonparametric trend estimation procedure of Section 2.2.1. This quantity will not be referred to as a correlation because correlation is defined for random variables, but in this case similarities between deterministic functions (annual cycles) have to be quantified. In addition, an overall measure called multiple association measure (MAM) characterizing how well the annual cycle of the slope of a pollen concentration trend can be represented by a linear combination of annual cycles of slopes of climate variable trends was also introduced. MAM varies between zero and unit approaching the unit under increasing accuracy of this above mentioned representation. Technically, MAM is calculated as a multiple correlation between a random variable and a number of other random variables, but again it should not be considered as correlation. AM and MAM are based on elementary considerations of linear algebra (see e.g. chapter 5.15 in Meyer 2001) because an annual cycle of slopes of daily trends covering an n-day period can be considered an n-dimensional vector. AM and MAM relate to angle between the vector corresponding to the annual cycle of the slope of a pollen concentration trend and the hyperplane defined by vectors corresponding to the annual cycles of slopes of climate variable trends.

MAMs do not necessarily harmonize with RP and EP for the given taxa. EPs were determined using RPs based on the ecological indicators of the species-pool; hence, these indicators are in strong association. These latter two plant associated indicators count (a) with the intra-taxonic species change, (b) with a higher range of species (species in and around the Carpathian basin), (c) with the transformation of the abiotic features of habitats, (d) with the moving capability of the species and (e) with the rescue effect of habitats due to special microclimates. At the same time, MAMs consider only the climate sensitivity of the taxa for a given time period, area and their species-pool. Furthermore, RP and EP are suitable to detect regional changes for longer (centuries, millennia) time periods, whereas MAMs can be used for observing local changes for shorter (decades) periods (Tables 1, 3, 4).

2.2.5. Factor analysis and special transformation

Factor analysis identifies any linear relationships among subsets of examined variables and this helps to reduce the dimensionality of the initial database without substantial loss of information. First, a factor analysis was applied to the initial datasets consisting of 9 variables (8 explanatory variables and 1 resultant variable defined by the daily *Ambrosia* pollen concentration) in order to transform the original variables to fewer variables. These new variables (called factors) can be viewed as latent variables explaining the joint behaviour of past and current meteorological elements – current *Ambrosia* pollen concentration variables. The optimum number of retained factors can be determined by different statistical criteria (Jolliffe 1993). The most common and widely accepted one is to specify a least percentage (80%) of the total variance in the original variables that has to be achieved (Liu 2009). After performing the factor analysis, a special transformation of the retained factors was made to discover to what degree the above-mentioned explanatory variables (4 climatic variables in the past and the same 4 climatic variables on the actual day) affect the resultant variable (daily *Ambrosia* pollen concentration), and to give a rank of their influence (Jahn and Vahle 1968). When performing factor analysis on the standardized variables the factor loadings received are correlation coefficients between the original variables and, after rotation, the coordinate values belonging to the turned axes (namely, factor values). If the resultant variable is strongly correlated with the factor and an influencing variable is highly correlated with the same factor, then the influencing variable is also highly correlated with the resultant variable. Accordingly, it is advisable to combine all the weights of the factors, together with the resultant variable, into one factor. Namely, it is effective to rotate so that only one factor has great load with the resultant variable. The remaining factors are uncorrelated with the resultant variable; that is to say, are of 0 weight (Jahn and Vahle 1968). This latter procedure is called special transformation.

3. RESULTS

3.1. Trend analysis

Only a few trends have been clearly identified compared to the total number of annual MK tests performed (Table 2). It is not surprising as the inter-annual variability of the characteristics studied is quite high, while the size of the data set is quite small. Therefore, MK tests are performed and linear trends are estimated for each particular day of each pollen season of all 19 taxa considered using 11-element pollen concentration data sets corresponding to the 11-year study period. This kind of trend analysis provides information on the annual cycles of trends. In the absence of a trend for each day of the pollen season, the MK test values are distributed normally with zero expectation and unit variance. Therefore, deciding on the existence of a trend is identical with the problem of deciding whether the annual mean of daily MK test values corresponds to the expectation zero. The classical *t*-test has been simplified for the purpose as the variance is known (unit), but modified based on the autocorrelations among the consecutive MK test values. First order autoregressive (AR(1)) models are used to describe these autocorrelations. Averaging values of daily slopes of linear trends over the pollen seasons gives rates of change of the total annual pollen counts (TAPC). Note that the trend analysis carried out on a daily basis detects much more significant trends of TAPC than the trend analysis on an annual basis (Table 2).

Table 2 Change in the total annual pollen count (TAPC) (pollen grains·m^{-3} / 10 years), annual peak pollen concentration (APP) (pollen grains·m^{-3} / 10 years), start, end and duration of the pollen season (days / 10 years) calculated by using linear trends. Significant values on annual basis are denoted by *** (1%), ** (5%) and * (10%). Significant values on daily basis are denoted by +++ (1%), ++ (5%) and + (10%).

Taxa	Mean total annual pollen counts	TAPC	APP	Pollen season		
				Start	End	Duration
Alnus	505	-214	-59*	18	16	-2
¹***Ambrosia***	7826	**-1170**	**230**	**14***	**-9**	**-22**
Artemisia	772	-61	-133	-4	15	19
Betula	901	-60	0	-1	2	3
Cannabis	432	47 +	-4	8	36**	28
Chenopodiaceae	854	-175 ++	-9	-2	3	5
Juglans	284	253 +++	30*	-8	-7	1
Morus	667	400 +++	44	-7	-4	3
Pinus	500	-194 +++	-20	-2	-1	0
Plantago	409	91 ++	3	-23**	-19	4
Platanus	400	271 ++	48	-7	-3	4
¹**Poaceae**	2552	**176**	**43**	**-10**	**17***	**27*** **
¹***Populus***	2322	**2981** +++**	**610****	**-2**	**3**	**4**
Quercus	423	236 +	25	4	9	5
Rumex	462	-505 +++	-45	-11**	3	15
Taxus	572	697* +++	59	-4	29***	32
Tilia	225	-65 +	-1	-4	-1	3
Ulmus	260	-160 +++	-12	5	-13	-18
¹***Urtica***	2200	**1183* +++**	**25**	**-13****	**18****	**31*****

¹**Bold:** taxa with the highest pollen levels

Needless to say, the daily MK test statistics have a big variability. Therefore, daily MK test values are smoothed with the nonparametric regression technique outlined in Section 2.2.1. In the absence of a trend for each day the estimated bandwidth is extremely large (practically infinite) producing a line close to zero because the local linear approximation to the annual cycle of the daily trends becomes globally linear. Hence, well-defined finite bandwidths obtained for every taxon indicate trends even for *Alnus, Ambrosia, Artemisia, Betula* and Poaceae, the 5 taxa not exhibiting overall trends on yearly basis at even 10% significance level. The nonparametric regression technique was used also to estimate annual cycles of the slopes of daily trends.

Trends of taxa (Table 2) related to trends of climatic variables (Fig. 1) can be explained as follows. *Alnus* and *Betula* occur around Szeged with very little populations (especially *Alnus*). Due to the tolerance range of these taxa increasing temperature and drying climate do not favour them, so their decreasing pollen trend would not be surprising as *Alnus glutinosa* – the only representative of this taxon appearing just in few bogs in the Great Hungarian Plain and parks in Szeged – and *Betula pendula* (planted in parks) like a wetter, more humid, balanced climate. Due to their low occurrences the decrease of their TAPC cannot be significant in the trends. However, we are now in a preliminary period of the climate change (Parry et al. 2007) to which they could have been already adapted. Furthermore, the trend back-shots (e.g. individual years with extreme high precipitation in the decreasing trend) could ensure enough water for their survival and adaptation, but it is questionable whether these back-shots will be enough if the trends continue in the future.

Pinus show a clear decreasing trend as a result of non-suitable choice of species because foresters and gardeners plant non-heat tolerant *Pinus* species in many cases. In the forest plantations of Kiskunság sand-ridge the co-plantation of *Pinus sylvestris* favouring a wetter, cooler climate and the more heat tolerant sub-Mediterranean *Pinus nigra* is common. The increasing temperature and the lack of water, especially in summer does not suit *Pinus sylvestris* and a substantial decrease of TAPC for *Pinus* can only be partially compensated by the increase of pollen counts of *Pinus nigra*.

TAPC for *Tilia* show a slight decreasing tendency. This taxon is not widely represented in the forests of the Great Hungarian Plain, but it is quite common in the parks and gardens of Szeged city. Of the Tilia species *Tilia platyphyllos* is often planted, which tolerates the warmer and drier climate less compared to *Tilia cordata* and *Tilia tomentosa*, which are more heat tolerant, especially the latter. *Tilia tomentosa* is represented along the Illyrian-Dacical pincer which is a route for sub-Mediterranean species approaching the Carpathian basin from the south. Note that the *Tilia* species can be found as ornamental vegetation mainly around Szeged, but they also occur within a 100-150 km range in natural forests in the surroundings of Szeged (Mecsek Mountain and South Transdanubian Hills west from Szeged, Banatian and Partiumian Mountains east of Szeged in Romania and Fruska Gora Mountains in Serbia, south of Szeged).

The lack of humidity and the increasing temperatures can be a limiting factor also for *Ulmus* as a notable decrease in its TAPC was observed. Stocks of its most common species *Ulmus minor* grow in dry places without shading trees like oak; they appear several times alone alongside roads and channels. This species together with *Ulmus laevis* can be found in the hard-wood floodplain forests as well. These taxa can also occur in parks where *Ulmus glabra* is sometimes planted. *Ulmus* is a spring pollinating species. A warming may involve higher spring temperatures and maximum temperatures. Its pollination season therefore can begin earlier and can last longer during this season mainly because in springtime no limitation of available groundwater can be detected. From the melted snow, from the springtime rainfall and even from the floods enough water is available for this genus. However, in dry places the lack of shading trees, while in floodplains the absence of floods and the lower level of the summer groundwater can limit their pollination.

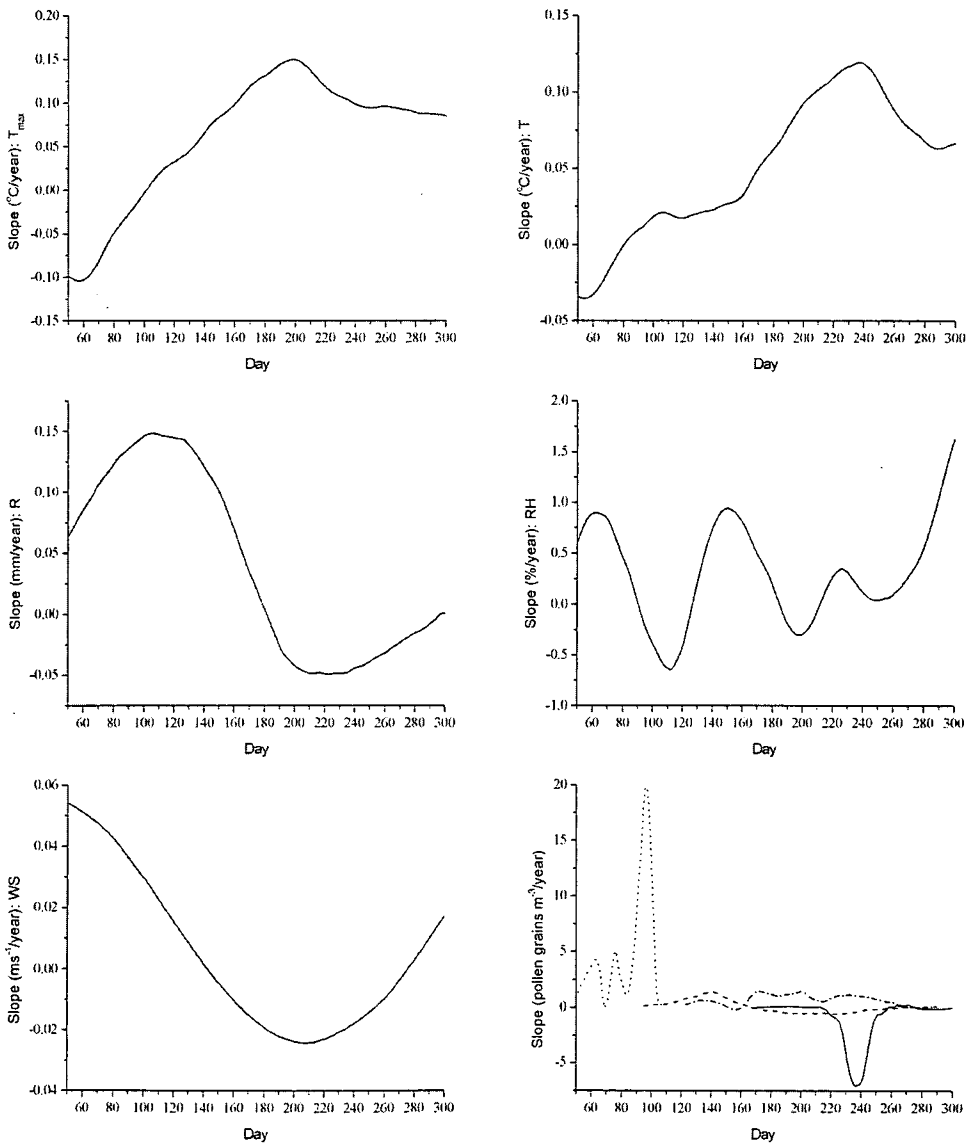

Fig. 1 Annual cycles of the slopes of daily linear trends for maximum temperature (T_{max}), mean temperature (T), rainfall total (R), relative humidity (RH) and wind speed (WS) for *Ambrosia* (solid), Poaceae (dash), *Populus* (dot) and *Urtica* (dash dot)

Change of TAPC for *Artemisia,* Chenopodiaceae and *Rumex* calculated on yearly basis is not significant. However, Chenopodiaceae and *Rumex* show decreasing trends when calculating on daily basis. These plants are typical species of young fallows, which appeared after the change of political system at the beginning of 1990s, especially in sand landscapes. However, due to spontaneous regeneration facilitated by grazing and mowing these new stocks began to disappear as these sand fallows turned into sand steppe grasslands (Deák 2010) and only the populations associated with natural habitats or settlements remained. At the same time, the abandonment of arable lands have decreased during the last 10 years as the extension of fallows was reduced by in-buildings and forest plantations, respectively. The strong decrease of *Rumex* can be explained by the fact that *Rumex* (especially *Rumex crispus*) often appears in the summer in depressions covered with inland water in springtime, which were transformed into arable lands. The lack of rainfall can hence reduce their stocks. However, wetter years do not favour the pollination of this genus since the plants' anther is not dry enough to open, furthermore rainfall can wash out its pollen from the air.

In contrast, TAPC of *Plantago* shows a clear increase, which can also be explained by the above-mentioned regeneration processes of fallows. *Plantago* species (especially *P. media* and *P. lanceolata*) are typical plants of old fallows regenerating into sand steppe grasslands, but also occur frequently in urban grasslands. It is typical that weeds of *Artemisia*, Chenopodiaceae and *Rumex* disappear in the later stages of fallow-succession, while steppe species like *Plantago* appear especially in the treated (mown, grazed) fallows. The fallows of the sand-ridge around Szeged have apparently reached the stage when *Plantago* became more frequent.

The duration of the pollen season of Poaceae is significantly increasing due to the warming climate, but TAPC exhibits no significant trend, which can also be in association with the regenerating fallows. The older fallows are all characterized by a huge coverage of grasses, so fallow regeneration led to a slight extension of grasslands during the last 10 years. In warmer years the pollination season of Poaceae can be substantially longer (Makra et al. 2012), but without higher pollen concentrations due to decreasing summer rainfall amounts.

Populus indicates a substantial increase of TAPC. This can be the result of its wide climate tolerance as both wet- (e.g. *P. nigra* and *P. canescens*) and drought tolerant species are represented in the landscape. Especially *Populus alba* living in floodplains, sand lands and parks shows a great adaptation potential. *Populus* (both wild and cultivated types) were planted widely in the sand lands west from Szeged and in the floodplains. Plantation of these species has not yet stopped during the last 10 years. Besides the locust-tree *(Robinia pseudo-acacia)* they are the most favoured trees for the plantation of forests. The stands planted in the last decades are in mature state, so they can pollinate on a high level.

Quercus (mainly *Quercus robur*) was not planted so widely during the last 10 years, but mainly in the 1960s and partly in the 1970-1980s significant oak plantations appeared southeast from Szeged in the saved-side floodplains and in the active floodplain of river Maros. The stands became more and more mature during the last decades, so they are on the level of their full pollination potential. As *Quercus robur* is a continental species with wide climate tolerance the increasing temperature can help its generative processes limited by the available water. These forests produce the average pollen count of this habitat-type. It must also be considered that these forests are managed. In a young forest there are smaller trees producing a certain amount of pollen. Some of them are then cut off in order to enhance the growth of the healthier individuals. They grow higher but the number of trees decreases significantly and so no major pollen count increase is expected due to their growing age. This is the reason why only a weakly significant increase in their pollen release occurs. Climate variables and pathogens can have a more important role in controlling the pollen counts from these stands and these two factors are also associated.

Surprisingly, the TAPC of *Taxus* showed a remarkable increase during the last 10 years. This species does not appear in natural communities around Szeged, only in parks and gardens. *Taxus baccata* – as a representative of this taxon in Szeged – is a Western European species favouring a more humid, balanced oceanic climate, which is warmer in the winter and springtime compared to the continental climate of Hungary. However, this trend is influenced by the city since the spring begins earlier and a longer pollination period with more pollen grains is expected due to the urban heat island. In this way, freezing temperatures can occur beyond the city, while inside above-zero temperatures are more typical.

Highly significant increase was observed for TAPC and the duration of the pollen season of *Urtica*. *Urtica dioica*, the only representative of this species around Szeged, has a wide climate tolerance. It can be found both in dry and wet habitats. The under-use of urban habitats, the frequent plantation of locust-tree *(Robinia pseudo-acacia)* and the increasing area of fallows also contributed to the expansion of their population. Their pollination is also promoted by increasing maximum temperatures facilitating an earlier start and later end of its pollen season.

Growing trends were observed for all heat tolerant, non-endemic taxa. TAPC of *Cannabis* (originated from South Asia) shows just a slight increase, but stronger increase was observed for *Juglans*, *Platanus* (originating from the Mediterranean) and *Morus* (originating from East Asia).

Ambrosia (represented only with one species) shows no significant trend as a moderate warming is favourable for this taxon, but the lack of available water during the hottest summer period can limit its pollination as the plant concentrates on preserving water and maintaining its vegetative life functions instead of the generative. *Ambrosia* appears year by year in stubble fields, especially in sand landscapes and in abandoned places around settlements. The populations of young fallows represent just a smaller part of their population in the landscape.

3.2. Analysis of the individual taxa based on MAM, RP and EP

Possible future change of taxa due to the anticipated climate change based on RP, EP (Table 3) and MAM (Table 4) can be explained as follows. *Alnus, Betula* and *Taxus* are endangered species in their existence according to their RP (***), as well as they are highly sensitive according to their MAM values (+++). This is because they live on the edge of their distribution area in Hungary. Hence, global warming can affect them negatively since they cannot tolerate warm and dry climate for a longer time and they can become extinct in several habitats and other competitors can be more successful. Especially *Alnus* is sensitive to the lack of water but the urban heat island can help its pollination as the pollen season can start earlier. *Betula* favours a much cooler climate according to its distribution area and climate tolerance indicators. Therefore, *Betula* adapted to cooler springs does not tolerate earlier springs with higher temperatures. The anticipated warmer climate may thus reduce its pollen release. Increased temperatures can be more severe limiting factors for *Betula* than the lack of water considering its existence.

Ambrosia is unaffected according to its MAM value. However, its higher potential increase is expected due to its ecological indicator values and high climate-tolerance. Namely, this genus can adapt well to dry and hot conditions, but is highly influenced by future land use.

Artemisia species are heat tolerant, so their EP is high; even Mediterranean and more continental species could appear in the Carpathian basin. The EP of agricultural weeds can be high on fallows that appear fast in all landscapes in unfavourable weather conditions for farming. *Artemisia* pollen is partly released by *Artemisia santonicum*, a natural dominant species of Artemisia short grass alkali steppes – main habitats of saline grasslands formed on loess (Deák 2010). These habitats and this species are proved to be very climate-sensitive – in contrast with *Artemisia* weeds. Its reason is the leaching out of their solonetz soils, due to the drainage of saline grasslands and the decrease of rainfall resulting in the decrease of salty groundwater-table.

Table 3 Association measure ([a]AM) between the annual cycles of the daily slopes of pollen concentration trends and the annual cycles of the daily slopes of climate variables trends

Taxa	T_{min}	T_{max}	T	R	TR	RH	WS	[b]MAM
Alnus	0.718*	0.775*	0.742*	0.313	-0.028	-0.620*	-0.455	0.992
[1]*Ambrosia*	**0.100**	**0.207**	**-0.641***	**0.398**	**0.049**	**0.087**	**0.223**	**0.827**
Artemisia	-0.249	0.676*	-0.486	0.140	-0.004	-0.230	-0.049	0.998
Betula	-0.689*	-0.192	-0.544*	-0.663*	-0.006	0.542*	0.070	0.973
Cannabis	0.602*	-0.559*	0.763*	-0.531*	-0.152	0.106	-0.147	0.993
Chenopodiaceae	0.071	0.306	-0.869*	0.644*	0.047	0.112	0.307	0.965
Juglans	0.271	-0.392	-0.466	0.613*	-0.129	-0.726*	0.452	0.925
Morus	0.329	-0.668*	-0.874*	0.821*	-0.216	-0.893*	0.684*	0.978
Pinus	0.093	0.144	0.241	-0.269	-0.160	-0.294	-0.079	0.963
Plantago	0.183	-0.642*	-0.093	0.337	-0.131	0.371	0.490	0.947
Platanus	0.308	-0.265	-0.354	0.368	-0.020	-0.576*	0.328	0.948
[1]Poaceae	**-0.088**	**-0.649***	**-0.816***	**0.826***	**-0.057**	**0.309**	**0.643***	**0.959**
[1]*Populus*	**0.361**	**0.358**	**0.395**	**0.407**	**-0.093**	**-0.378**	**-0.349**	**0.869**
Quercus	-0.046	0.165	0.360	0.616*	-0.076	-0.640*	-0.062	0.911
Rumex	-0.093	-0.026	0.450	-0.244	-0.060	-0.365	-0.087	0.979
Taxus	0.618*	0.305	0.428	0.446	0.010	0.009	-0.264	0.985
Tilia	0.284	-0.378	-0.171	0.327	0.062	-0.106	0.428	0.973
Ulmus	0.381	0.565*	0.462	0.063	-0.069	-0.766*	-0.256	0.934
[1]*Urtica*	**-0.467**	**0.612***	**0.451**	**-0.396**	**0.076**	**-0.580***	**-0.705***	**0.827**

[1]**Bold:** taxa with the highest pollen levels;
T_{min}: minimum temperature (°C), T_{max}: maximum temperature (°C), T: mean temperature (°C), R: rainfall (mm), TR: total radiation ($W \cdot m^{-2}$), RH: relative humidity (%), WS: wind speed ($m \cdot s^{-1}$);
[a]AM (association measure): reflects the strength of the relationship between the annual cycle of the daily slopes of pollen concentration trends and the annual cycles of the daily slopes of climate variables trends for each individual taxon;
[b]MAM (multiple association measure): describes how well the annual cycle of the slope of the daily pollen concentrations can be represented by a linear combination of the annual cycles of the slopes of the daily climate variable trends. MAM varies between zero and one, approaching one with increasing accuracy of this above-mentioned representation (Meyer 2001);
*AM >|0.5| indicates a strong association

Cannabis is a heat tolerant species but too high maximum temperatures can be a limit for its pollen production due to water shortage. Future drier conditions are expected during its pollen season, though the June rainfall peak (Medard-day rainfall) overlaps it.

The MAM of Chenopodiaceae indicates high sensitivity, but its response to climate change varies according to its species as it has a wide range of species-pool. Both increase and decrease of its species-pool are expected. These plants frequently appear in areas affected by inland water around Szeged that can disappear due to a drying climate.

Juglans being heat tolerant shows a potential increase due to warming, and according to its MAM, has medium climate sensitivity. Rainfall is a major limiting factor. Warming can help this species as it happened in interglacial times, but a certain minimum rainfall is required. This species cannot be seen over the driest areas of the Mediterranean, but still has a relatively large EP in Hungary.

Table 4 Climate change related indicators and significance of the different pollen season characteristics for each individual taxon

Taxa	RP	EP	[2]MAM	[3]TAPC by linear trend	[4]APP	[5]Pollen season			[6]TAPC via daily linear trend
						onset	end	duration	
Alnus	***	-2	+++		(-10)				
[1]*Ambrosia*	*	**2**	+			**(+10)**			
Artemisia	*	2	+++						
Betula	***	-2	+++						
Cannabis	*	0	+++				+5		(+10)
Chenopodiaceae	* **(few taxa)	1	+++						-5
Juglans	*	2	++		(+10)				+1
Morus	**	-1	+++						+1
Pinus	**	-1	+++						-1
Plantago	* **(few taxa)	1	++			-5			+5
Platanus	*	2	++						+5
[1]Poaceae	* **(few taxa) ***(few taxa)	**1**	+++				**(+10)**	**+1**	
[1]*Populus*	* **(few taxa)	**1**	+	**+5**	**+5**				**+1**
Quercus	* **(few taxa)	1	++						(+10)
Rumex	* **(few taxa)	1	+++			-5			-1
Taxus	***	-2	+++	(+10)			+1		+1
Tilia	* **(few taxa)	1	+++						(-10)
Ulmus	* **(few taxa)	1	++						-1
[1]*Urtica*	* **(few taxa)	**1**	+	**(+10)**		**-5**	**+5**	**+1**	**+1**

[1]**Bold:** taxa with the highest pollen levels;
[2]**MAM (multiple association measure):** + low sensitivity; ++ medium sensitivity; +++ high sensitivity;
[3]**TAPC by linear trend:** change in the total annual pollen count calculated by using linear trends;
[4]**APP:** change in the annual peak pollen concentration calculated by using linear trends;
[5]**Pollen season:** change of start, end and duration of the pollinations season calculated by using linear trends;
[6]**TAPC via daily linear trend:** change in the total annual pollen count calculated by using daily linear trends;
[3, 4, 5, 6:] ±1, ±5: a significant increasing/decreasing trend at the 1%, 5% probability levels; (±10): a tendency of trend at the 10% probability level

Morus is assigned to the moderately endangered category (**). Lack of rainfall and too high temperature are a barrier for their pollen production during their pollen season (summer). Its AM and MAM values emphasize that decreasing rainfall can decrease their pollination intensely. On its original distribution area in China, high temperatures are accompanied with spring-time or monsoon rainfalls. This high precipitation amount is missing in Central Europe. Hence, *Morus* try to preserve as much water as possible in summer.

Pinus is endangered moderately according to its RP (**) but MAM shows much higher sensitivity (+++). This is because *Pinus sylvestris* representing a big portion of this species cannot tolerate warming climate. However, change in species composition, plantation and the appearance of Mediterranean species can make this genus more adaptive for the expected changes.

Plantago, Quercus and *Ulmus* have medium sensitivity (++) according to their MAM values and due to their diversified species-pool they can react well to climate change with intra-taxonic species changes. RP values show that they are moderately endangered or not endangered, and for heat tolerant, sub-Mediterranean or continental species further expansion can be awaited at the expense of present species. It can be expected mostly for genera *Ulmus* and *Quercus,* where more heat tolerant species also exist in the landscape or around the Carpathian-basin.

A medium sensitivity indicated by MAM (++) is observed for *Platanus*. It stands warm climate, but a shortage of water can be a limiting factor. This species appears mainly in mountain valleys alongside streams in the Mediterranean, where a certain amount of water is available. It has a potential for expansion in Hungary but not in every landscapes.

Poaceae show high sensitivity according to MAM (+++), since the available water and high temperature can mean limits for them. However, the species-pool of this family is the widest among the studied plant groups, so there will be species to substitute the actual grasses and even species from the Mediterranean and the more continental areas can reach the Carpathian-basin in the future. This means a high risk for the present species, but intra-taxonic re-assemblage could happen. Shortage of water and too high temperatures can cause lower pollen production in natural grasslands and also in crops produced in arable lands. Certain species in certain places and time periods can suffer from climate change, but the change in species composition will give good chance for the survival of this family.

Rumex is moderately endangered in the Szeged region as it can give a wide range of responses to climate change according to its species-pool. Since *Rumex* species around Szeged live rather in semi-humid conditions favouring inland water covered areas (see *Rumex crispus*, the most common *Rumex* species around Szeged) climate change could affect them intensely due to water shortage.

The *Tilia* genus can give a wide range of responses according to its species-pool. Potential increase, especially for *Tilia tomentosa*, is expected in the Great Hungarian Plain, but this heat tolerant species currently occurs only in the parks of Szeged. The existing species-pool is not favourable for the expected climate change. Especially *Tilia platyphyllos* characterized by high sensitivity according to its MAM (+++) will not stand the warming. *Tilia cordata* could survive better, but its natural stock is very small.

Urtica and *Populus* have a wide climate-tolerance, so they are not climate-sensitive according to MAM. Both genera could increase their population in the future. They are not endangered or only certain species are moderately endangered by warming. *Urtica dioica* is not endangered according to its RP and even population increase is expected. For the extremely rare *Urtica kioviensis* living in boggy wetlands major decrease is expected in the

Carpathian basin. The better climate tolerance of *Populus* can be explained by the wide adaptation of its different species.

4. DISCUSSION AND CONCLUSIONS

Climate change can modify the pollen season characteristics of different allergenic taxa in diverse ways and can exert a substantial influence on habitat regions. In our best knowledge, only three previous studies (Clot 2003, Damialis et al. 2007, Cristofori et al. 2010) analysed comprehensive spectra of the regional pollen flora. The present study analyses one of the largest spectra with 19 taxa. Our study can be considered unique in the sense that trends of pollen concentration data for each taxon and those of all seven climate variables are calculated on a daily basis. This kind of trend analysis provides information on annual cycles of daily slopes of trends.

On a yearly basis only *Populus, Taxus* and *Urtica* show a significant increase of the total annual pollen count. *Populus* and *Juglans* display the most important increase, while *Alnus* exhibits the biggest decrease of the annual peak pollen counts. Poaceae and *Urtica* show a significant increase in the duration of the pollen season. Based on the 5% level, 11 of the 19 taxa indicated significant trends of the total annual pollen count, and 7 of these 11 trends is increasing on a daily basis (Table 2). Phenological characteristics (onset, end and duration of the pollen season) show changes only in 8 (10) out of 57 cases (19 taxa x 3 phenological characteristics) at 5% (10%) significance level. Here, Poaceae and *Urtica* are the most important with notable changes in at least two characteristics. Our conclusions are in good agreement with those of several previous researches. For Thessaloniki (Greece), the total annual pollen counts, as well as the daily peak pollen counts show significant increasing trends for the majority of taxa, but there are no important changes for the phenological characteristics (Damialis et al. 2007). Looking at a bigger region of Central Europe, for Zurich, Switzerland (Frei 2008, *Betula*), as well as for Vienna, Austria (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollen concentrations for most of the pollen types have been increasing. Furthermore, for Zurich (Frei 2008, *Betula*), Poznań, Poland (Stach et al. 2007, *Artemisia*) and Vienna (Jäger et al. 1996, *Alnus, Corylus, Betula, Pinus* and *Ulmus*) the pollen season starts earlier, the daily maximum pollen concentration has increased (Frei 2008, *Betula*) and the days of peak pollen counts occur earlier (Stach et al. 2007, *Artemisia*).

Note that all taxa examined in the study are families or genera involving a number of species. Accordingly, analysing pollen season and phenological characteristics of a family or genus instead of given species involves a high variability of pollen season data. An observed trend in the above characteristics incorporates the variability of a given parameter for all species belonging to a given taxon, but this variability is influenced by meteorological variables. The important role of sunshine hours is stressed here, since its high values enhance pollen production (Valencia-Barrera et al. 2001, Kasprzyk and Walanus 2010). We found increasing trends (at 5% significance level) in the total solar radiation, relative humidity and wind speed. Temperature and rainfall do not display overall significant trends, but the smoothing of daily MK test values shows stages of positive and negative trends within the year for these latter two variables as well (Fig. 1).

Based on an association measure (AM) – introduced to characterise the strength of the relationship between annual cycles of daily slopes of pollen concentration trends and those of climate variables trends – the individual taxa were placed into three categories according to their climate sensitivity defined by a multiple AM (MAM). These are: (1) high sensitivity: MAM > 0.950, involving 11 taxa (*Artemisia, Cannabis, Alnus, Taxus, Rumex, Morus, Betula, Tilia,* Chenopodiaceae, *Pinus* and Poaceae); (2) medium sensitivity: 0.900 < MAM ≤ 0.950, including 5 taxa (*Platanus, Plantago, Ulmus, Juglans* and *Quercus*); (3) low sensitivity: MAM ≤ 0.900, comprising 3 taxa (*Populus, Ambrosia* and *Urtica*) (Table 3).

Risk potential (RP) and expansion potential (EP) due to climate change are compared to the MAM for each taxon (Tables 3, 4). The association measure alone cannot contain or express the climate change related indicators. However, all taxa having the lowest climate sensitivity (+) are non-endangered (*) and, except for *Ambrosia,* are characterized by a moderate EP. At the same time, for all endangered taxa (***) (even if just one species is endangered within a given taxon) MAMs indicate high sensitivity (+++). Accordingly, the association measures follow well the climate change related indicators indicating that climate parameters are important elements of the environment for the taxa examined.

However, airborne pollen concentration can be influenced not only by current values of meteorological elements but their past values as well. As it is hard to distinguish between the effect of current and past values of the meteorological variables no attempt has been made to determine the relative weight of these two components in influencing the measured current pollen concentration. The procedure proposed here was performed only for *Ambrosia,* the most allergenic of all taxa considered. Current meteorological elements were characterized by actual values, while past meteorological elements by cumulative values of daily mean temperature, daily relative humidity, daily total solar radiation and daily precipitation total, respectively. These four elements were considered since ragweed pollen concentration displays a significant positive correlation with the daily mean temperature (Bartková-Ščevková 2003, Štefanič et al. 2005, Peternel et al. 2006, Puc 2006, Kasprzyk 2008), but it shows a negative correlation with the daily relative humidity (Bartková-Ščevková 2003, Puc 2006, Kasprzyk 2008). Daily mean total solar radiation is also found to be an important predictor of local ragweed pollen levels (Laaidi et al. 2003, Štefanič et al. 2005, Oh 2009). *Ambrosia* pollen grains are negatively correlated with rainfall (Barnes et al. 2001, Kasprzyk 2008), furthermore Déchamp and Penel (2001) found that heavy rainfall reduced the risk of ragweed pollen allergy. In order to assess the effect of the antecedent and current meteorological conditions on the current pollen concentration, the 1^{st}-day, 2^{nd}-day, … , 93^{rd}-day values of both the pollen concentration and the four meteorological elements of the current pollen season were taken. (The duration of the ragweed pollen season in Szeged lasts from July 15 until October 15, namely 93 days.) Association between pollen concentration and the four meteorological variables characterizes the role of current weather conditions. Values of these meteorological variables were then cumulated for 272-day, 271-day, …, 1-day periods starting 272 days, 271 days, …, 1 day before the actual day of the actual pollen season. This is because there are 272 days between the end of the previous-year pollination season and the beginning of the actual pollen season. Hence, altogether 272 data sets were produced and factor analysis with special transformation was performed for each of them.

The main conclusions for *Ambrosia* as an example are as follows (Fig. 2). The total weights (summarized absolute values) of the factor loadings for the past meteorological variables (dashed line) are gradually increasing from day 272 until day 123 reaching a maximum value of 0.498. From this day until present the effect of the past climate parameters influencing daily *Ambrosia* pollen level decreases, though two local maxima (days 82 and 21) occur. The total weights of the factor loadings for the current climate parameters (solid line) are very low from the day 272 until the day 138. Then, they are increasing steeply reaching their top values between days 62 and 50. During the last 50 days until the start of the current *Ambrosia* pollen season the total weights are sharply decreasing. Note that these findings are valid only for variations of daily *Ambrosia* pollen concentrations accounted for by the above eight explanatory variables and nothing is known about the variance portion not explained by these variables. On the whole, in agreement with our preliminary expectations, past climate has a higher weight far from, while current climate has greater importance close to the time of the current pollen release. The effect of the past climate is greater on the current *Ambrosia* pollen concentration from day 272 until day 77, while from this day until present the current climate has higher weight in influencing the current *Ambrosia* pollen level. The effect of the current climate begins to increase on day 138 (i.e. 138 days before July 15, corresponding to the date February 28) (Fig. 2). This date corresponds well to the fact that the germination ability of over 80% for *Ambrosia* pollen seeds is mostly measured from the second half of February (Hartmann et al. 2003). Under the climate conditions of Hungary the germination peak of *Ambrosia* pollen seeds occurs in April (Béres et al. 2005) indicating a good agreement with the fact that the effect of the current climate becomes predominant over the past climate influencing *Ambrosia* pollen release from day 77 (i.e. 77 days preceding July 15, corresponding to the date April 30. Further climate-related significance of these days (February 28 and April 30) is as follows. By the end of February daily mean temperatures have already been in a positive range. The weight of the past climate elements culminates in January-February. This denotes the important effect of temperature and precipitation as practically the only parameters of the past climate to be considered for *Ambrosia* pollen concentration as resultant variable in winter. The effect of autumn rainfall lasts until the end of February. As soon as photosynthesis starts, autumn and winter precipitation is gradually utilised by the plants and hence leads to the decrease of the role of precipitation as an element of the past climate and to the increase of the role of current rainfall. Additionally, from the 2nd half of April mean and maximum temperatures suddenly increase that substantially contributes to the plants producing organic material for their generative processes.

Besides meteorological variables, pollen concentrations are influenced as well by agricultural and social factors (Makra et al. 2005) including urbanisation, so-called "green meadow investments" (new investments in former agricultural areas) and newly built motorways. Land eutrophication facilitating higher pollen production is not characteristic in an agricultural area consisting of small private plots for the Szeged agglomeration. A more important factor is that large industrial areas have come into use; housing estates as well as motorways were constructed in the region during the period investigated. Stripping agricultural lands for building purposes could mean an expansion of neglected areas that contributes to an increase of habitat regions of weeds and hence to an increase in pollen production. It would be important to distinguish between the changes in atmospheric pollen concentrations resulting from the effect of climate change and changes due to land use changes. The effect of climate can be characterised by meteorological variables, while land use changes can be described by changes in the ratios of agricultural areas, industrial areas, urban areas, forests, meadows, vineyards, orchards and fallows. Applying an appropriate statistical procedure (such as factor analysis with special transformation) the weight of both climate-related and land use related components of atmospheric pollen concentrations could be estimated. However, information on the changes in land use is only available for years 1990, 2000 and 2006 in the CORINE Land Cover Database (www.eea.europa.eu) and hence such a statistical procedure cannot be performed.

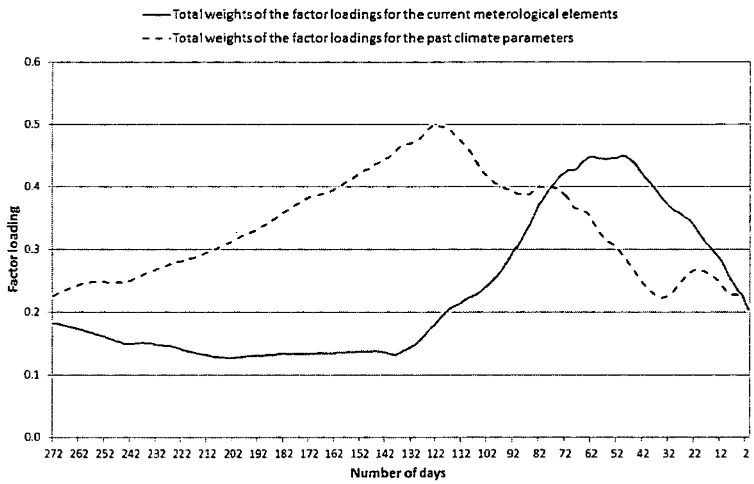

Fig. 2 Total weights of the factor loadings for the current and past meteorological elements influencing current *Ambrosia* pollen concentration

Nevertheless, the role of land use changes in the pollen release of the taxa considered was also evaluated in the following simple way. CORINE Land Cover maps for the Szeged area are available with a 100 km radius around the centre of the city for the years 1990, 2000 and 2006. For the Szeged area, from short- to medium-range pollen transport involving local pollen dispersion has higher impact on daily *Ambrosia* pollen concentration compared to long-range pollen transport (Makra et al. 2010). Hence, an area of 100 km limit of medium-range transport (Makra et al. 2010) was considered. Then, in the centre of the radius a square was fit to the circle with its sides touching the circle that covers an area of 40,000 km^2. Changes in the individual land use cover categories were determined in m^2 from year 1990 to year 2000, as well as from year 2000 to year 2006. These changes were then expressed in the unit of the total area covered by the square. To sum up, changes in land use displayed $1.68 \cdot 10^{-5}$ % from year 1990 to year 2000, while $5.39 \cdot 10^{-3}$ % from year 2000 to year 2006. Therefore, land use changes did not influence pollen concentration of any taxa considered over the Szeged area in the period examined (www.eea.europa.eu/publications/COR0-landcover).

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ASSESSMENT OF THE BIOCLIMATIC CONDITIONS OF A POPULAR PLAYGROUND BY THE MICROCLIMATE MODEL ENVI-MET

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Summary: The paper introduces a thermal comfort examination carried out in a well-attended playground located in the city centre of Szeged (Hungary). The aim of this study is to find the optimal land cover and vegetation options of the study area by means of numerical simulations. For this evaluation the modelled micro- and bioclimatological conditions of a typical summer day (12th July 2011) were analyzed. The thermal and radiation environments of the playground were quantified by one of the most popular bioclimatological comfort index Predicted Mean Vote (PMV) and the Mean Radiant Temperature (T_{mrt}). The simulations of the investigated parameters were performed by the microclimate model ENVI-met. The obtained results proved that the modelled area provided a variety of thermal conditions for the visitors due primarily to the different land covers. Moreover this paper emphasizes the important effect of the vegetation on the human thermal sensation.

Key words: thermal comfort, Predicted Mean Vote (PMV), Mean Radiant Temperature (T_{mrt}), ENVI-met, land cover

1. INTRODUCTION

The climatological and bioclimatological conditions are modified in urban environment compared to the rural areas (Unger 1999), and even inside a city in micro-scale these conditions are changing rapidly following the urban surface characteristics. The setup of the urban surface characteristics is related with the work of planners, architects and urban planners therefore they have an influence on the local and micro-scale climate conditions. Urban planning in general and within it the planning of urban green spaces is a very complex process and it has several climatological aspects. The final shape of an urban park is defined by the aspects of the architecture but this final setup determines the microclimate of that area and finally the thermal comfort of the visitors. As a result of the thermal comfort conditions the visitors or users of the urban park may alter their opinion about it. If the park is perfect from an architectural point of view, but heat stress frequently occurs there, the visitors will avoid the area.

In the last decades there were numerous researches in the topic of microclimate and thermal comfort, therefore now several methods and software are available to predict the microclimate conditions of an urban park when it is only in the planning stage, or before the construction starts (e.g. Lehme and Bruse 2003, Gulyás et al. 2006, Chow et al. 2011, Fröhlich and Matzarakis 2012). This study is an example for this type of micro-scale modelling, which can give useful information for the architects to make sure that the constructed open space or park has in the end the optimal or best setup in several aspects.

2. MATERIAL AND METHODS

2.1. Description of the study area

The present human thermal comfort examinations took place in the centre of Szeged, located in the south-eastern part of a Central-European state, Hungary (46°N, 20°E). The investigated approximately 3300 m^2 large area is one of the most modern and well-attended playgrounds in the city. In this open the space children can choose among several toys, jungle gyms as well as swings, and 20 benches offer seating for the visitors. In the eastern part of the playground a cottage is situated where the children can play even in bad weather (Fig. 1).

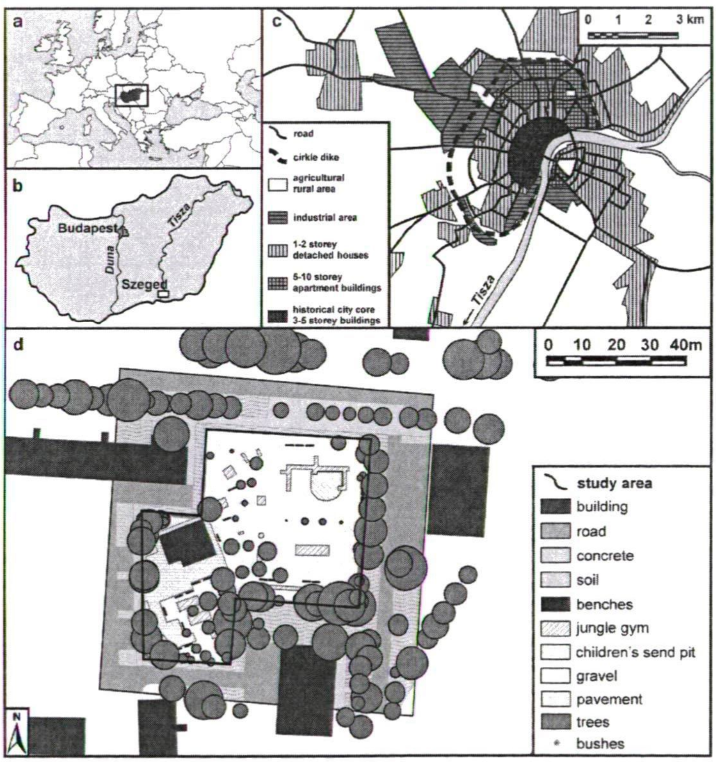

Fig. 1 Geographical location of Hungary (a) and Szeged (b); Detailed maps of Szeged (c) and the investigated playground (d)

The surface of the area is primarily covered by light-coloured paving stone that protects the playing children from greater injuries. Other land cover can only be found in the following parts of the playground: the children's sand pits are filled with sand, and the immediate vicinity of the cottage and the southeast corner of the playground are paved. The amount of vegetation is considerable (primarily deciduous trees), however, they are mainly located at the boundaries of the study area. Therefore during forenoon and in the early afternoon hours a large part of the playground is exposed to the sunlight (Fig. 2).

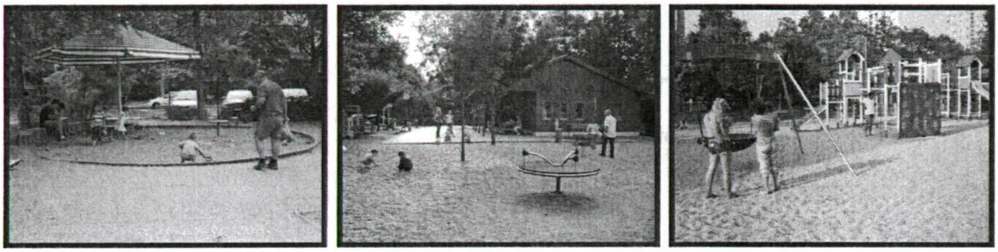

Fig. 2 Photographs of the investigated playground

2.2. Methods

The present study applies the ENVI-met model in order to compare the effects of different land covers and designs on the micro- and human comfort conditions. ENVI-met is a three-dimensional non-hydrostatic climate model which is able to model the interactions in the surfaces-atmosphere-vegetation system with relatively high temporal (10 min) and spatial (0.5-10 m) resolution (Bruse and Fleer 1998). The simulation required two groups of input data: the configuration file (.cf) contains the basic settings and the necessary meteorological parameters of the simulation while the area input file (.in) includes the morphological elements (buildings, plants, land covers etc.) of the investigated area.

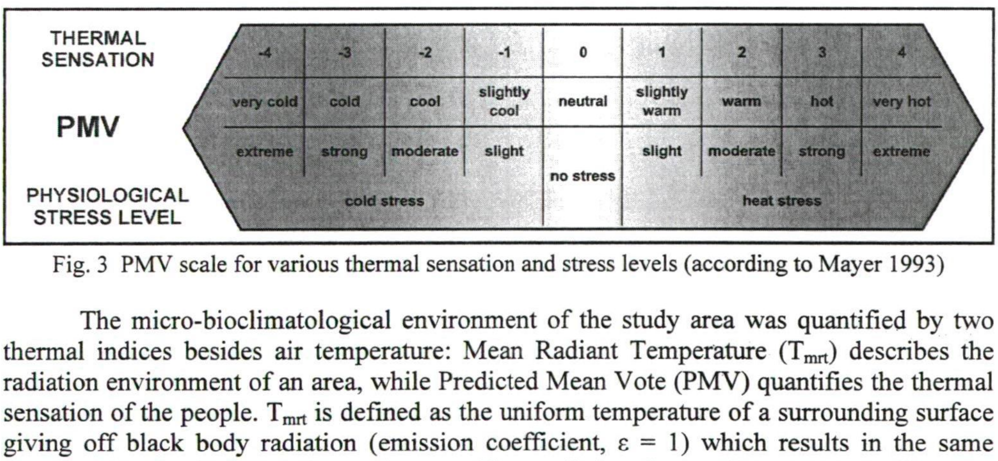

Fig. 3 PMV scale for various thermal sensation and stress levels (according to Mayer 1993)

The micro-bioclimatological environment of the study area was quantified by two thermal indices besides air temperature: Mean Radiant Temperature (T_{mrt}) describes the radiation environment of an area, while Predicted Mean Vote (PMV) quantifies the thermal sensation of the people. T_{mrt} is defined as the uniform temperature of a surrounding surface giving off black body radiation (emission coefficient, $\varepsilon = 1$) which results in the same energy gain of a human body as the prevailing radiation fluxes (Höppe 1992). The other index PMV predicts the mean assessment of the thermal environment for a large sample of human beings by values according to the originally seven-point (from -3 to +3) ASHRAE comfort scale. This comfort scale at around 0 is characterized as comfortable, higher and lower values indicate increasing probability of thermal discomfort as well as stress due to heat and cold conditions, respectively. In (extreme) real weather conditions, PMV can be higher than +3 or lower than -3 (Mayer and Höppe 1987, Mayer 1993) (Fig. 3)

Table 1 The basic input parameters of the simulation

Parameter	Input value
Temperature (K)	296
Relative humidity in 2 m (%)	58
Wind speed in 10 m (m/s)	3.4
Wind direction (°)	325
Spec. humidity in 2500 m (g/kg)	7
Roughness	0.1
Total simulation time (h)	18
Start simulation	00:00:00

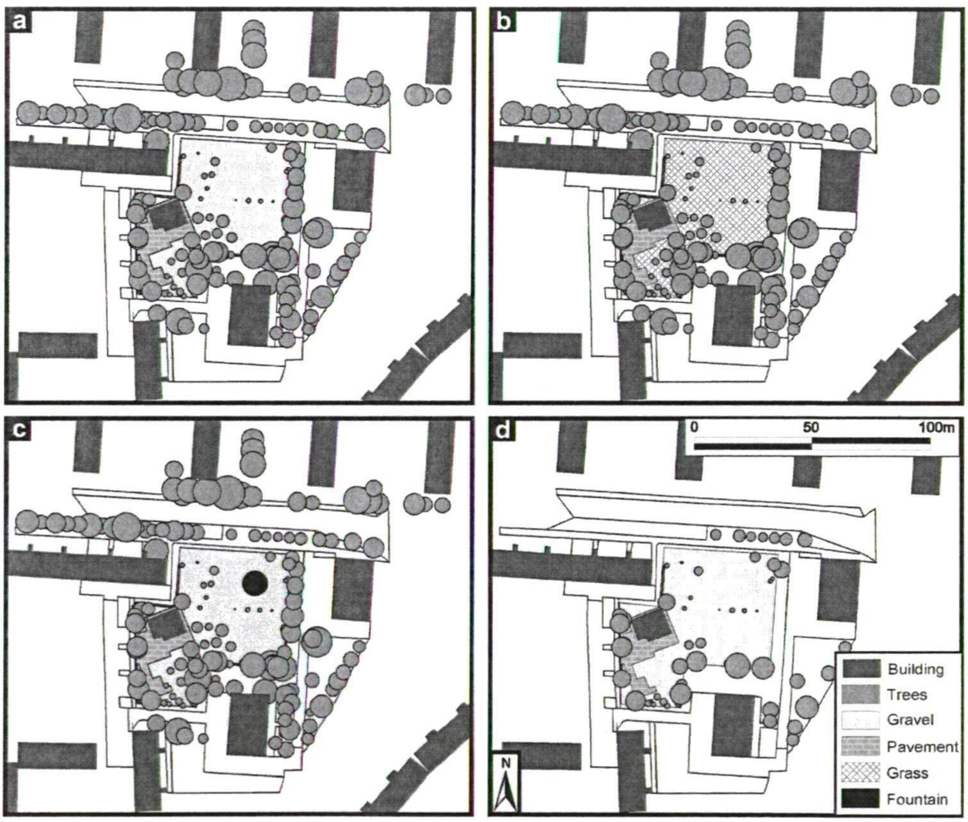

Fig. 4 The schematic pictures of the four simulation scenarios

The simulation was run on a typical hot, cloudless summer day (12th July 2011), because the differences in the thermal and microclimatic environment can clearly be observed at this time. As parameters of the modelling procedure, 18 hours (from 12 a.m. to 6 p.m.) of total simulation time and a spatial resolution of 1.5 m were adjusted in ENVI-met. The simulation results were related to the bioclimatological reference height of

1.1m. Table 1 shows the basic settings of the simulation and the necessary meteorological data obtained from the meteorological station of the Hungarian Meteorological Service situated in the city centre of Szeged (Unger and Gál 2011).

Four simulation scenarios were created in ENVI-met to find the optimal land covers and design for the studied playground. *Scenario 1* contains the base area without any modification (Fig. 4a). In *scenario 2* grassy land cover was employed instead of gravel (Fig. 4b). In case of the *scenario 3* a little fountain (lake) was virtually built in the north-eastern part of the playground, but the original land covers were retained (Fig. 4c). Finally, in *scenario 4* a part of the vegetation was removed (Fig. 4d). This paper demonstrates the results of these modifications at a selected time (11 a.m.) on the investigated simulation day, when the differences of the microclimatic conditions can be easier observed.

3. RESULTS AND DISCUSSION

3.1. Thermal and radiation characteristics of the base area without modification

In the first part of the analysis, the results of scenario 1 were examined. Fig. 5a shows that the spatial patterns of the simulated air temperature were relatively homogeneous, differences were not larger than a few tenths of degree Celsius all over the area. Higher values (about 24°C) occurred in the northern areas. In the eastern and southern parts, where the vegetation is significant, the temperature was slightly cooler (23.4–23.6°C).

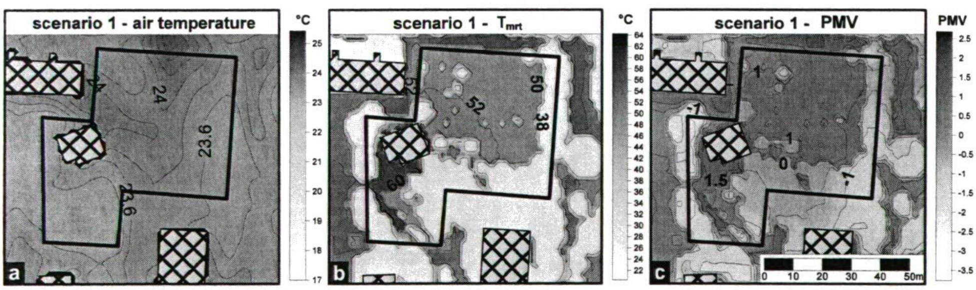

Fig. 5 The thermal features of the modelled area without modification (scenario 1)

However, the maps of T_{mrt} and PMV (Figs. 5b and 5c) representing the spatial distribution of the radiation environment and thermal sensation were much more diverse, proving the complexity of these bioclimatological indices compared to air temperature. At the same time, these maps illustrate the effects of the different land cover and vegetation types on the human thermal sensation. The spatial distributions of T_{mrt} and PMV values were analogous, which supported the fact that the radiation factor plays a very important role in human thermal sensation at this time of the year.

Duo to the strong direct radiation in this period as well as the significant reflected radiation from the surface of the pavement, the highest T_{mrt} values (60°C) occurred in the vicinity of the cottage. In the middle parts of the area T_{mrt} values slightly decreased (50–52°C), however significant drop in the values can only be found in the shade of the trees

(38°C). The heat stress map (PMV map) illustrates that the most unpleasant part (PMV = 1.5, slightly warm – warm thermal sensation) of the playground is situated on the pavement due to the above mentioned increased radiation. However, under the trees where both the incoming and reflected radiation fluxes were minimal at this time, the thermal conditions were more comfortable and the values approached to PMV = 0 (neutral thermal sensation) and the PMV = -1 (slightly cool thermal sensation).

3.2. The effects of the area modification on the thermal conditions

In order to compare the scenarios, difference maps were created. In these maps the modelled values of the base case (area without modification, Fig. 5) were subtracted from the corresponding values of the given scenario (scenarios 2-4), thereby the effects of the modification can be more easily observed.

According to Fig. 6a, the air temperature slightly increased in scenario 2 (grassy surface instead of gravel), which can be explained by the different water-holding capacity of the gravel and the grass. However, this difference did not exceed 0.15°C anywhere, consequently the influence of the modifications in scenario 2 were practically negligible.

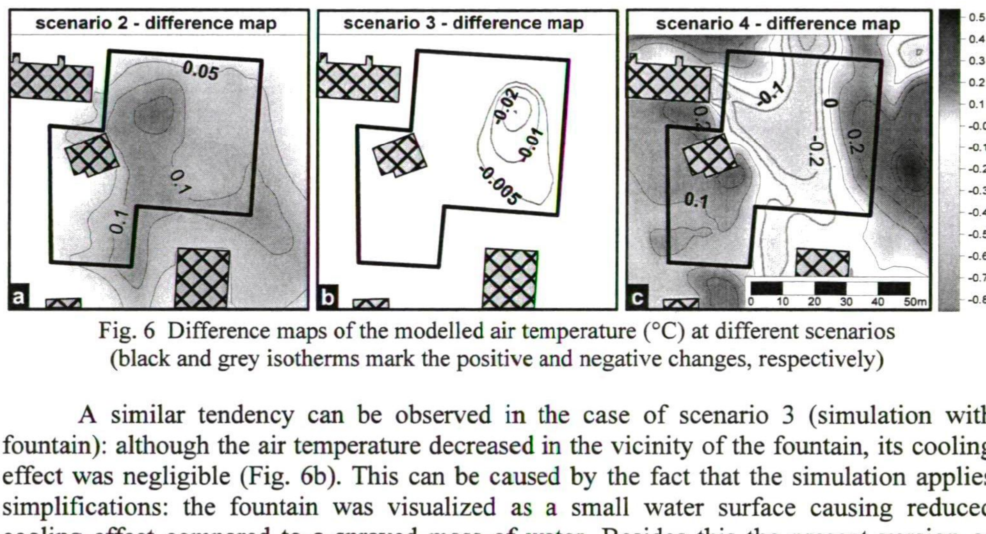

Fig. 6 Difference maps of the modelled air temperature (°C) at different scenarios (black and grey isotherms mark the positive and negative changes, respectively)

A similar tendency can be observed in the case of scenario 3 (simulation with fountain): although the air temperature decreased in the vicinity of the fountain, its cooling effect was negligible (Fig. 6b). This can be caused by the fact that the simulation applies simplifications: the fountain was visualized as a small water surface causing reduced cooling effect compared to a sprayed mass of water. Besides this the present version of ENVI-met may not be able to render such fine adjustments as employed in scenarios 2 and 3. On the map of scenario 4 (simulation with reduced vegetation), the values of difference varied between -0.2 and 0.2°C (Fig. 6c). Positive differences, i.e. increase of air temperature mainly occurs at the boundary of the study area, where some parts of the vegetation were removed. In the north-western part of the simulation area a large group of trees was removed (Fig 4d), which gave way to the prevailing northwesterly wind (Table 1). The incoming wind cooled down the environment, therefore the temperature in the middle part of the area slightly decreased.

As illustrated in Fig. 7, the variation in the thermal radiation conditions was hardly significant on the first two difference maps (scenario 2 and 3). In the case of scenario 2 the deviations of the T_{mrt} values not even achieved 1°C (Fig. 7a). In scenario 3 the effect of the fountain was limited and expanded only to the area of the water surface (Fig. 7b). However, the map of scenario 4 highlighted that the modification of the vegetation caused significant changes in the radiation environment (Fig. 7c). The dark patches on the map indicate places of removed vegetation, where the increase of T_{mrt} values exceeded even 20°C due to the strong incoming radiation.

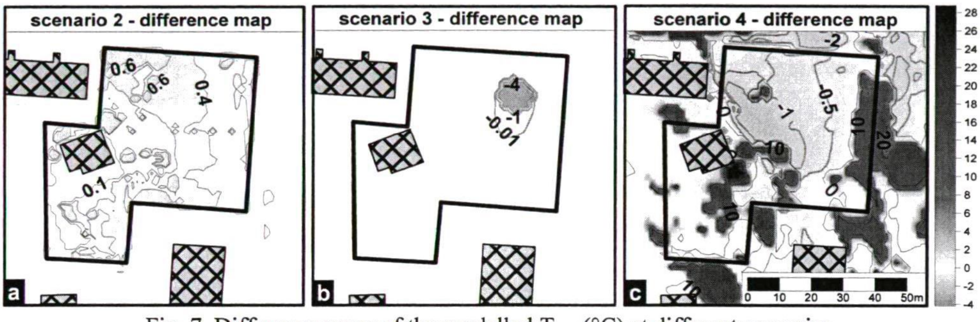

Fig. 7 Difference maps of the modelled T_{mrt} (°C) at different scenarios

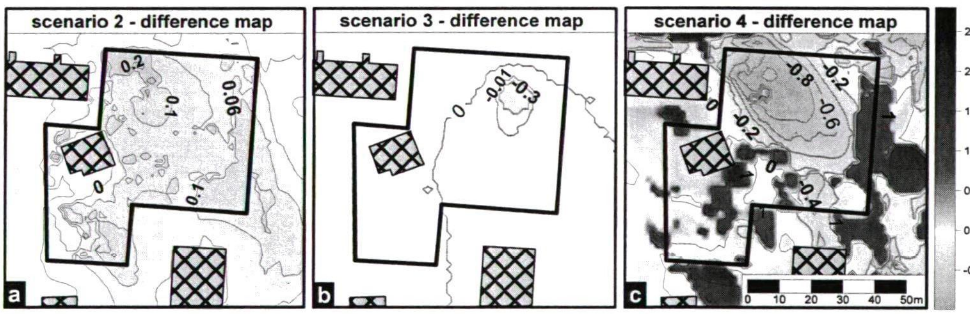

Fig. 8 Difference maps of the modelled PMV at different scenarios

Although the air temperature and T_{mrt} values are important indicators of thermal comfort, PMV can predict and quantify how people sense the thermal conditions of a given area. Therefore the analysis of the spatial patterns of the PMV values is explicitly pronounced in the investigated scenarios. Fig. 8 shows the difference maps of the modelled PMV values. According to our simulation results, scenarios 2 and 3 caused negligible changes in the thermal environment (Figs. 8a and 8b). The slight increase of PMV values (0.06 – 0.2 PMV) in scenario 2 and the reduction of that (-0.01 – -0.3 PMV) in the vicinity of the fountain (scenario 3) are almost imperceptible to humans. However the difference map of scenario 4 shed light on the important role of vegetation in thermal comfort (Fig. 8c). Namely, the removal of trees from certain parts of the playground caused an increase of as much as 1 PMV, so these areas shifted into another, warmer thermal sensation category (slightly warm instead of neutral). In the middle part of the playground, slightly cooler PMV values (-0.2 – -0.8) can be found due to the above mentioned north-western wind. Consequently, in some cases the appropriate position of the trees may contribute to the ventilation of the area providing more comfortable environment in otherwise stressful conditions.

4. CONCLUSIONS

Some preliminary results of a thermal comfort investigation based on the simulation of micro- and bioclimatological conditions were presented discussing the effect of different land covers on the thermal comfort sensation. The effects of four simulation scenarios were compared by the simulations of ENVI-met, where the thermal environment was characterized by bioclimatic indices T_{mrt} and PMV besides air temperature.

The results of the examination show that a grassy land cover (scenario 2) and a virtual fountain (scenario 3) caused only slight variations in the thermal condition. Contrary to the expected results, the influence of the surface cover modifications of these two scenarios was not significant according to the obtained maps. This can probably be explained by the fact that it is difficult to treat these minor changes in the model area using the present version of the simulation. However, the outcome of scenario 4 revealed the importance of the effect of the vegetation on the thermal sensation. The reduction of the number of trees increased the thermal load in the playground, but at the same time an increased ventilation occurred on the area by the prevailing wind.

The aim of this study was to emphasize the importance of the modelling procedure in the process of urban planning and to give a hand in the development of a comfortable urban environment.

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TENDENCIES AND DIFFERENCES IN HUMAN THERMAL COMFORT IN DISTINCT URBAN AREAS IN BUDAPEST, HUNGARY

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Summary: In the Hungarian capital city, Budapest, no detailed human thermal comfort examinations have been performed until now despite the fact that the analysis of urban climate from a human comfort point of view is extremely timely. The objective of the present study is to evaluate the differences and changes of the thermal comfort conditions in the last half century based on the measurements of two meteorological stations located in different environments: one in the central urban area (Local Climate Zone 2 – 'compact midrise') and the other in the suburbs (between Local Climate Zones 6 – 'open lowrise' and A – 'dense trees'). The thermal comfort was quantified using a popular bioclimate index, the Physiologically Equivalent Temperature (PET) for four characteristic times of the day: 6, 12, 18 and 24 UTC in the period of 1961–2010. Then the thermal comfort differences between the stations according to three climatic normal periods (1961–1990, 1971–2000 and 1981–2010), and the tendencies detected among the periods were also analyzed. For the last decade, 2001–2010, more detailed hourly-resolution investigations were carried out. According to the results, the annual and seasonal averages of PET are higher in the central area in each climate normal period and at all dates; furthermore the PET averages increase during the consecutive 30-year periods. The results proved that warm stress has become more frequent; however, the cold heat load decreased in both examined area. Investigating the hourly data, in terms of the whole ten-year period, a higher ratio of hot stress and less cold stress can be observed in the central area.

Key words: urban area, local climate zones, 50-year data series, thermal comfort, Physiologically Equivalent Temperature (PET)

1. INTRODUCTION

Due to the rapid urbanization more and more people are exposed to the modified climate of urban areas where the thermal conditions (in addition to air pollution and noise) can be stressful for humans. This tendency increases the importance of the investigations related to the thermal comfort conditions in our cities and their changes, hereby providing help for the urban planners, the public health authorities, or the tourism operators in their work. The urban planning or decision-making processes often do not consider the human biometeorological aspects in Hungary. A complete change of attitude is needed in this field because thermal comfort is one of the determining factors of human health and the quality of life, and therefore it is crucial to maintain its optimum level.

In Hungary there are extensive urban climatological studies in progress in Szeged, South Hungary. These studies include detailed examinations of human thermal comfort too (e.g. Unger 1999, Gulyás et al. 2006, 2010). As an example, research in terms of the relationship between the attendance and comfort conditions of public areas have been conducted for several years (Kántor and Gulyás 2010, Kántor and Unger 2010, Égerházi and Kántor 2011).

Budapest (capital of Hungary) has nearly 2 million inhabitants and additionally, the urban thermal environment affects the quality of life of at least 200.000 commuters each day, too. Even so, very few studies were implemented in this direction in Budapest until now (e.g. Németh 2011). The aim of this research is therefore to establish a detailed human comfort investigation in this large urban environment based on the currently available data. To achieve this, we characterize and quantify the bioclimatological differences between two meteorological stations situated in the central area and the suburbs. In addition, tendencies in human comfort conditions in the last half-century are also under investigation.

2. STUDY AREAS AND METHODS

2.1. Study areas

Budapest is situated in central Hungary (47°N, 19°E). In this study the measured data of two meteorological stations of the Hungarian Meteorological Service were used (Fig. 1). One station (Budapest-Kitaibel Pál utca) is located in a densely populated central urban area of the city. According to the 'Local Climate Zone' classification system developed by Stewart and Oke (2012) this area belongs to the 'compact midrise' (LCZ 2). However, the location of this station is not ideal because the effects of the Buda Hills are already detected in its data. In addition, the measurement conditions have changed significantly since April 1985 as the previous regular, street-level measurements moved to the roof terrace of the central building of the Hungarian Meteorological Service. (Ambrózy et al. 2006). Nevertheless, we assumed that this station, due to its relatively central location, can represent the climate modification effects of the city centre relative to the other urban areas of Budapest.

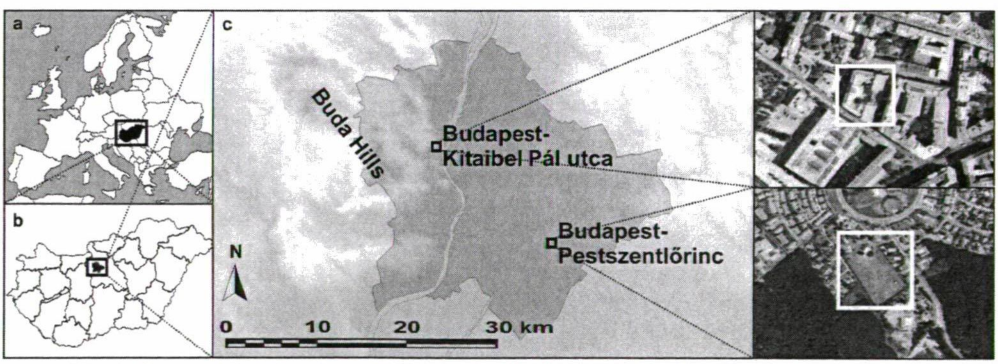

Fig. 1 Geographical location of Hungary and Budapest (a, b); locations of the examined meteorological stations (c) and areal photographs of their surroundings

The other station (Budapest-Pestszentlőrinc) is located in the suburban region between the areas classified as 'open lowrise' (LCZ 6) and 'dense trees' (LCZ A) (Stewart and Oke 2012). The measurements take place in a large observing garden, in regular conditions. During the examined period (1961–2010) there was no change in its location, so the data series can be regarded as homogeneous.

As Stewart and Oke (2012) state 'the urban-rural temperature difference, or UHI magnitude, is the most widely cited measure of city climate modification in the environmental sciences. It is also the most poorly represented.' Therefore, they proposed a new framework, where UHI magnitude is an LCZ temperature difference (e.g. $T_{LCZ\ 1} - T_{LCZ\ D}$), not an urban-rural temperature difference (ΔT_{u-r}). Our study follows this framework in the comparison of human thermal conditions in the above mentioned two urban areas of Budapest.

2.2. Methods

In order to characterize the human comfort conditions in the study areas one of the best known and most widely used bioclimate indices, the Physiologically Equivalent Temperature (PET) was applied (Matzarakis et al. 1999). PET is defined as the air temperature at which the heat budget of the human body in a typical indoor setting is balanced with the same core and skin temperature as under the actual, complex outdoor conditions to be assessed (Höppe 1999). The PET value ranges were defined according to different thermal perceptions for temperate climate (Table 1) (Matzarakis and Mayer 1996).

Table 1 Categories of the physiologically equivalent temperature values for different grades of thermal perception and physiological stress (Matzarakis and Mayer 1996). **The original ranges do not include these two* categories, *they are used in practice only in Hungary!*

PET (°C)	Thermal perception	Grade of physiological stress
above 41	very hot	extreme heat stress
35 – 41	hot	strong heat stress
29 – 35	warm	moderate heat stress
23 – 29	slightly warm	slight heat stress
18 – 23	comfortable	no thermal stress
13 – 18	slightly cool	slight cold stress
8 – 13	cool	moderate cold stress
4 – 8	cold	strong cold stress
0 – 4	very cold	extreme cold stress
–10 – 0	*frosty**	*extreme cold stress**
below –10	*very frosty**	*extreme cold stress**

The meteorological parameters necessary for the calculation of the PET (air, temperature, relative humidity, wind velocity and degree of cloud cover) were available at the mentioned stations. (As no visual observations are at 24 UTC in the case of the central urban (LCZ 2) station, the cloudiness data are missing here. These data are replaced by those of the other station.) There were some corrections in air temperature data derived from the roof level at this station. The measured wind speed data of both stations were transformed to the reference height of 1.1 m (the average height of an adult's gravitation centre) using a formula from Kuttler (1998). The calculations of PET were referred to a standard European 35-year-old, 1.75 m high, 75 kg weight, sedentary man, wearing clothing with a heat resistance of 0.9 clo.

In the examined period there were observations every six hours (6, 12, 18 and 24 UTC). Additionally, in the period of 2001–2010 the measurements are more detailed, which means that hourly data were available. The applied bioclimate index was determined at these times by means of the model RayMan. (Matzarakis et al. 1999, 2007). Then hourly, daily, 10-day, monthly, seasonal, annual and 30-year averages of PET were calculated from the PET values. Based on these values bioclimate diagrams of both stations were constructed where PET ranges are depicted according to Table 1.

3. RESULTS AND DISCUSSION

3.1. Diurnal and annual variations in the periods of 1961–1990 and 1981–2010

The first part of the analysis concerns the normal periods of 1961–1990 and 1981–2010 when the differences detected between the measuring points as well as among the periods were investigated. The bioclimate diagrams showing the frequencies of the PET categories have 10-day intervals.

According to Figs. 2 and 3, the number of cold stress days at 0 UTC in the period of 1961–1990 is less by 2.5% in the centre than in the suburban area. This difference increases to 5% in the period of 1981–2010. Thus, at night the inhabitants in the central area perceive less cold stress in winter than those in the suburbs. However, the heat load increased in the city centre in summer and therefore the people are generally less able to regenerate during the night. In mid-summer already the slightly warm heat stress category appears there in the second period (1981–2010). Presumably, the difference between the bioclimatic conditions of the measuring points is a consequence of the well developed urban heat island.

The tendency of differences between the stations is similar also at 6 UTC. In the two periods, the frequency of the warm stress is higher in the centre by 4.4% and 5.8%, respectively. For example in the summer mornings the relative frequency of moderate heat stress is around 10% in the city, while it is minimal in the suburbs.

In the early afternoon period (12 UTC) the city centre shows also a high heat load during the summer months, which means 8.8% and 10.3% higher frequencies in the two 30-year periods, respectively. The combined frequencies of the two most extreme thermal sensation categories (very hot and hot) are also higher here by 5.4% and 7.5%, respectively. Therefore, the everyday outdoor work can be adversely affected during the summer months in the city centre. Nevertheless, it is favourable to city dwellers that the cold stress is lower by 7.6% than in the suburbs, which further declines by 1% in the later period.

At 18 UTC a similar tendency can be observed but the difference is much smaller than in the mid-day period. At this time, the warm stress in the examined periods is higher by 3.3% and 4.4% in the centre, but the cold stress is lower by 5.1% and 6.3%. In summer, the evening relaxation or ventilation opportunity may be limited in the city which can have extremely negative effects on the human body. It should not be ignored that the relaxation may be even less effective in the high heat capacity, poorly ventilated homes (e.g. block of flats). Here much more unfavourable conditions can develop than outdoors.

In summary, at every time the city centre is affected by higher heat load and less cold stress with the largest differences found in early afternoon, even when the strongest heat stress prevails in summer and outdoor activities are really significant. The smallest differences appear in the evening and at night. Furthermore, according to the relative frequencies of PET categories an increasing tendency of warm stress can be observed in all cases during the investigated 20-year shift (Figs. 2 and 3).

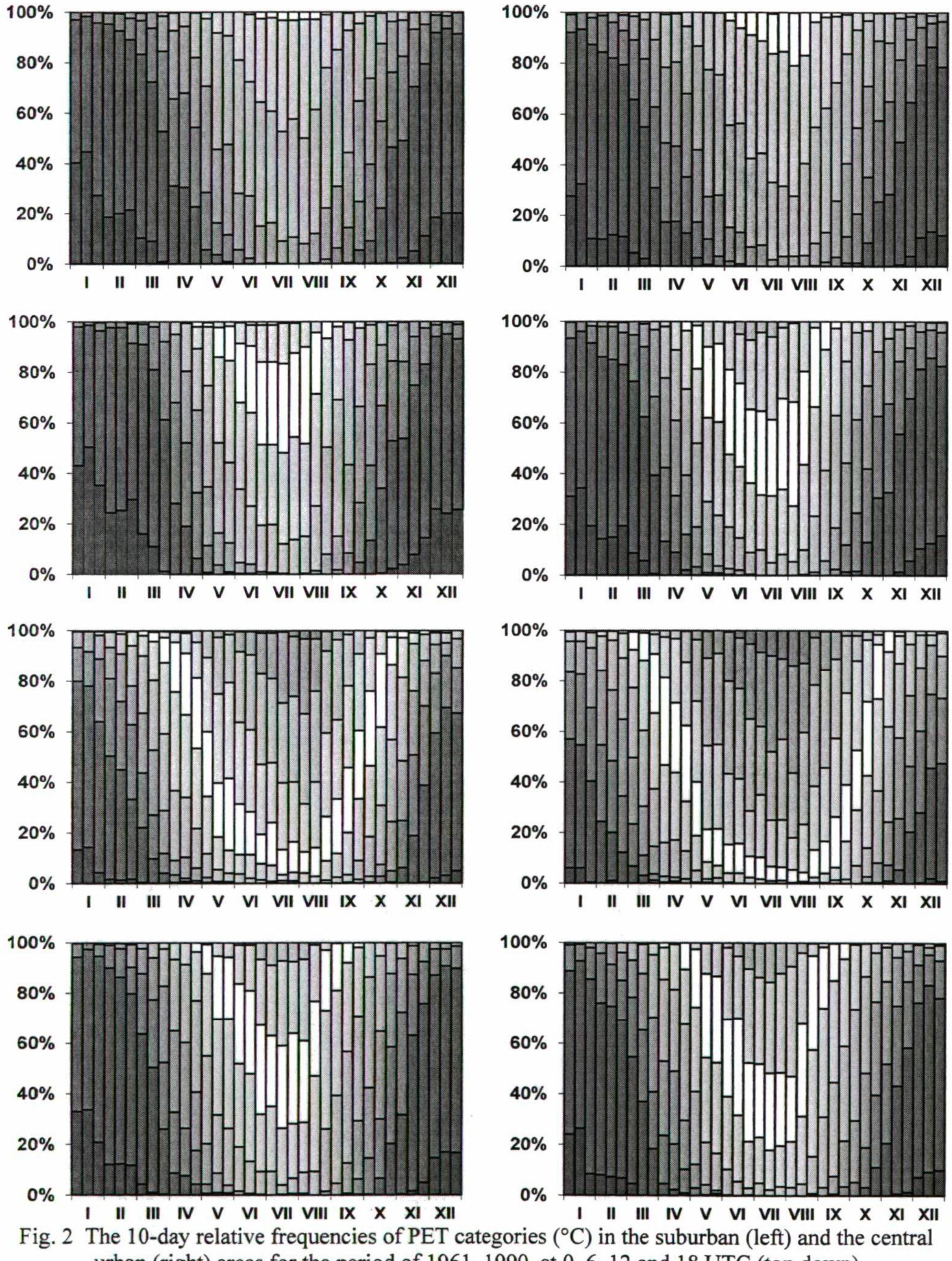

Fig. 2 The 10-day relative frequencies of PET categories (°C) in the suburban (left) and the central urban (right) areas for the period of 1961–1990, at 0, 6, 12 and 18 UTC (top down)

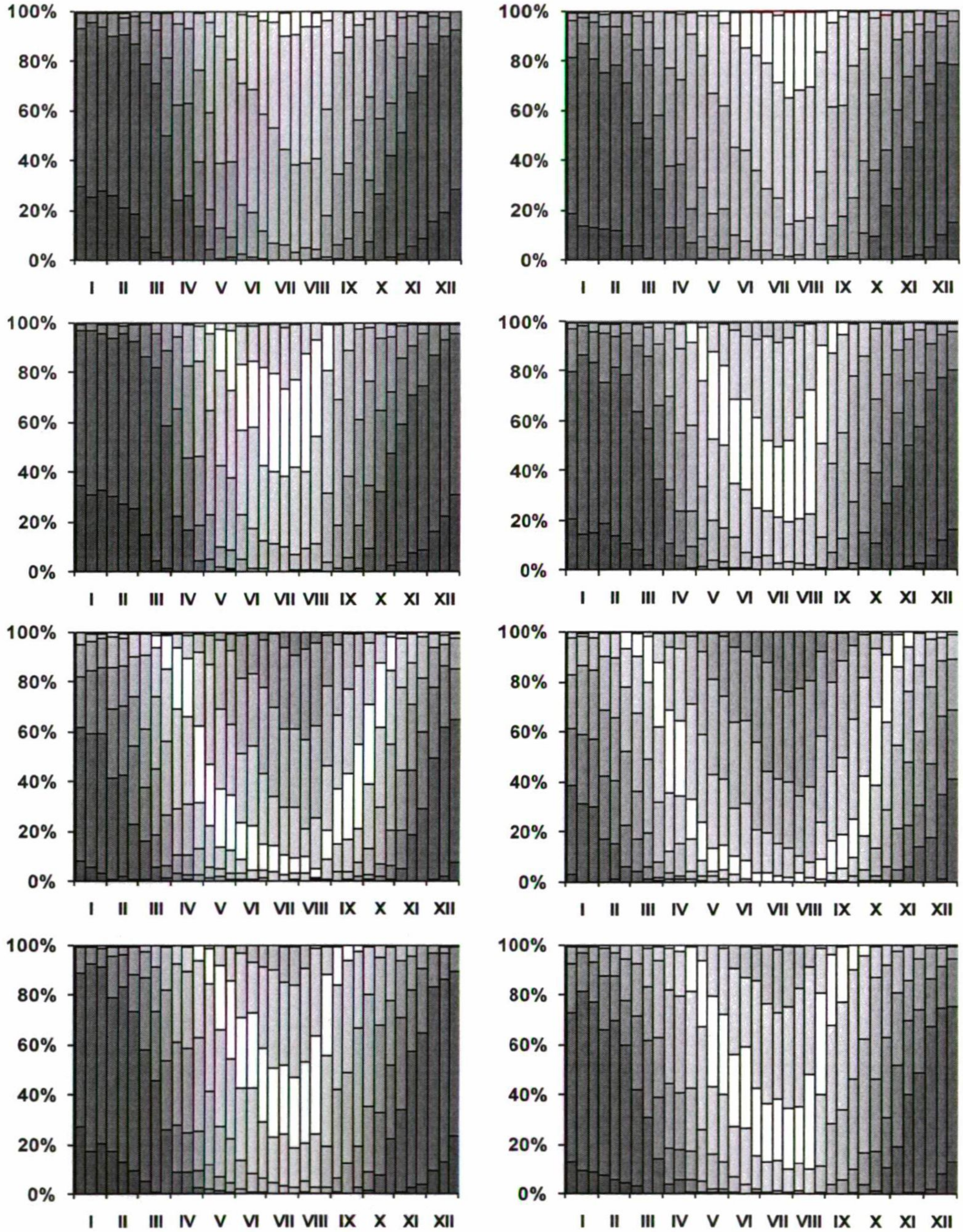

Fig. 3 The 10-day relative frequencies of PET categories (°C) in the suburban (left) and the central urban (right) areas for the period of 1981–2010, at 0, 6, 12 and 18 UTC (top down)

3.2. Hourly and seasonal variations in the period of 2001–2010

The characteristics of the intra-day changes of thermal comfort by seasons in the 2001–2010 period are analyzed in detail based on the hourly PET values. We considered the distribution of PET averages by days and hours (Figs. 4 and 5).

During the whole ten-year period, the average PET values are higher by 3°C in the city centre. The maximum PET is only slightly higher (0.9°C) here but the difference in the minimum value is much higher, about 5°C. Generally, at a given time a greater degree of hot stress and less cold stress can be observed in the centre by a PET category.

In late spring (Fig. 4), the city centre already has a significant ratio of warm sensation category and also the hot category appears, while in the suburbs the ratio of warm load is low. In summer, the hot stress becomes dominant at noon in the centre (Fig. 4). (Short decreases of the PET values observable in a few days' time can be related to weather fronts.) It should be noted that in summer evenings the warm stress decreases remarkably slowly in the centre keeping nights warmer than in the suburbs.

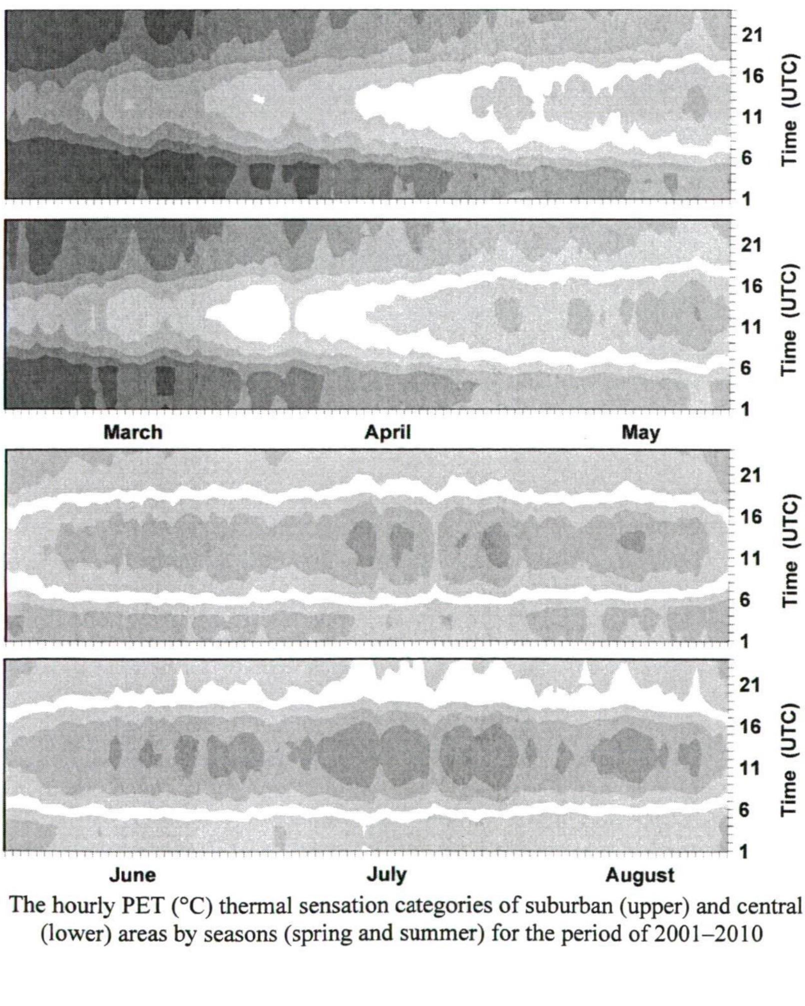

Fig. 4 The hourly PET (°C) thermal sensation categories of suburban (upper) and central urban (lower) areas by seasons (spring and summer) for the period of 2001–2010

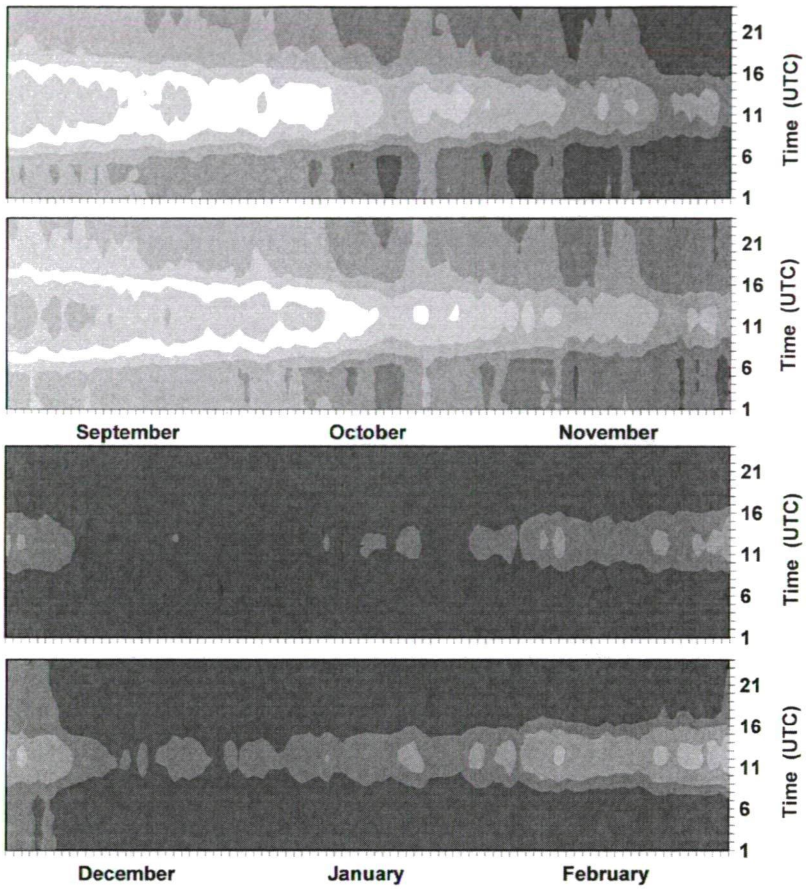

Fig. 5 The hourly PET (°C) thermal sensation categories of suburban area (upper) and central urban (lower) areas by seasons (autumn and winter) for the period of 2001–2010

In early autumn (Fig. 5), the warm category is already missing in the daytime and by the end of autumn the frosty (extreme cold stress) category becomes prevalent in the suburbs (except at noon). According to the ten-year average, the extreme cold stress is dominant in both areas in winter (Fig. 5), but during daytime the people in the city are affected by smaller cold stress. This may have a positive impact on the thermal comfort here.

3.3. Tendencies in the 30-year periods shifted by 10 years

We examined the annual and seasonal PET averages of the three climate normal periods (1961–1990, 1971–2000 and 1981–2010) by observation times in order to detect any changes in the differences between the two stations.

According to the obtained values, higher PET values occur in the centre in each period and all seasons, which is consistent with the previous results. The highest difference (~ 4°C) can be seen at noon in spring (Fig. 6), while the lowest (~ 2°C) can be observed at

18 UTC, in the same season. During the sequence of the shifted 30-year periods an increase in the centre-suburban difference can be detected in all observation times and seasons.

An additional characteristic is also noticeable (not shown): for the last 30-year period the average of PET increased slightly in both stations and each time in winter, or even decreased at 0 UTC in the suburbs. In order to find an explanation for this, we analyzed the 30-year averages of some input variables of PET (air temperature, relative humidity and wind speed). We found that the air temperature may cause this trend, because the mean temperatures are smaller at both station in the third 30-year period than in the earlier ones.

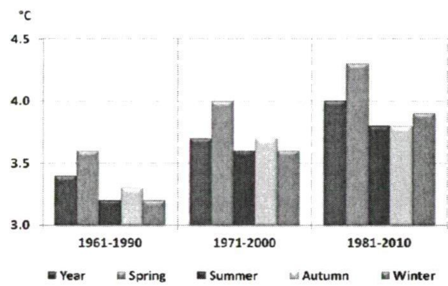

Fig. 6 Differences between city centre and suburban values of annual and seasonal averages of PET at 12 UTC

4. CONCLUSION

This study investigated the differences and changes of the human thermal comfort conditions in the last half century by comparing measurements of two meteorological stations located in different environments of Budapest. In the capital of Hungary only a limited number of bioclimatological investigations have been performed until now.

The following main conclusions can be drawn concerning the features, differences and tendencies of human comfort conditions characterized by the frequently used bioclimate index PET.

- According to the diurnal and annual PET variations in the periods of 1961–1990 and 1981–2010, the main features of the bioclimatic differences of measuring points are the same in all four characteristic observation times: the heat load is stronger and the cold stress level is less in the city centre than in the suburbs. The largest differences appear in the daytime period, while the smallest in the evening and at night. The detected trends between the two presented normal periods indicate that warm stress has become more common while cold heat load decreased in both stations at each examined time. Their effect on human comfort can be either advantageous or disadvantageous, depending on the season.
- As the hourly and seasonal variations in the period of 2001–2010 show, in general the central area is influenced by a higher degree of hot stress and less cold stress by a category of PET. The warmer nights detected in the centre in summer can affect the thermal comfort conditions particularly adversely.

- In terms of the annual and seasonal averages of PET in the three normal periods shifted by 10 years, there are higher values unambiguously in the centre and an increase in the centre-suburban difference can be detected at all observation times in all seasons.

The presumed reason for the received bioclimatic differences and tendencies is the fact that the intensifying built-up ratio and the detected global warming in the last decades together strengthened the urban heat island effect in the central areas, while in the suburbs, rather only the climate change may play a role in the detected increasing trend.

In relation to the obtained results it should not be ignored that the location of the central station in Budapest is not really ideal for urban climatological research. However, sufficiently long data series, which are necessary for analysing the urban climate and bioclimate, are not available. Therefore, in the near future, it is necessary to establish a few meteorological stations at street-level in the urban area, which would represent the different Local Climate Zones, which occur in Budapest better.

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DATA ON THE HYDROGEOGRAPHICAL CONDITIONS OF BARADLA CAVE: SEEPAGE AND DRIP WATERS

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Summary: This paper analyses the hydrological features of Baradla Cave. Together with the Slovakian caves the Baradla-Domica cave system is a UNESCO world heritage site and the preservation of karst water, as a drinking water reservoir is a very important task. First of all, the water balance (precipitation, infiltration water, seepage water and evapotranspiration water) of the catchment area was defined. Secondly, the changes in different physicochemical parameters (water temperature, pH, electric conductivity, dissolved oxygen content, redox potential and nitrate concentration) of karst water were defined by using stable and mobile monitoring sites after the rapid and slow melting of snow. The quality (chemical parameters) of dripping water was also examined during these periods. We found that the extreme water level fluctuations imply changes in water quality parameters that affect drinking water quality. Further monitoring would be particularly important since it provides an opportunity to understand the changes in trends and thus the future development of a more accurate protection strategy for the catchment area.

Key words: karst hydrogeography, karst water balance and quality, Baradla Cave, Hungary

1. INTRODUCTION

The Baradla-Domica Cave complex is a UNESCO world heritage site and it is under the protection of the Ramsar Convention. The cave system is located in the Hungarian-Slovakian borderland, in the Gömör-Torna Karst which is a geographically homogeneous region extending over 60.000 hectares. The area is divided into the Slovak Karst (northern part) and the Aggtelek Karst (southern part) areas that host more than 700 caves. The underground drainage system and most of the caves in the karst region were formed in the Middle and Upper Triassic limestones of the Silica Nappe since this type of bedrock is eminently prone to karstification. Limestones occur together with sandstones and shale pala. The cave system is a typical example of multi-level speleogenesis. Under the main passage two lower caves (Long Lower Baradla Cave and Short Lower Baradla Cave) evolve independently from each other.

The hydrogeographical study of the cave is of particular importance concerning the public water supply of the nearby villages. This paper presents some data provided by the hydrochemical monitoring that was started in 1980 and has been continuous since 2000 with the aim of analyzing the changes of seepage and infiltration waters.

2. MATERIALS AND METHODS

GIS and field data processing was based on the hydrological model of the cave. The analyses of infiltration water were carried out by using an YSI multiparameter water quality monitoring system. YSI probes were installed in the Styx and Acheron streams and water temperature, pH, electric conductivity, dissolved oxygen content, redox potential and nitrate concentration were measured continuously. Occasionally spot investigations were carried out. Drip water samples were collected in 500ml bottles and were analysed on the surface by an YSI device. The obtained data were evaluated by GIS methods.

3. REASULTS AND DISCUSSION

The Aggtelek Plateau is connected to the southern limestone belt of Silice Plateau. In the north erosion valleys separate the mountain tops dissected by low altitude dry doline valleys from the southern part of Silica Nappe. The southern boundary of Aggtelek Plateau is the covered karst area of Putnok Hill. In the east the Hideg Valley separates the limestone bed from the Galyaság. Different doline generations can be identified on the karst plateau. On the contrary, on the karstic tops and interfluves only a few dolines can be found. Dolines have transformed into uvalas on the catchment areas of Béke and Baradla caves and in Hideg Valley.

To the west Aggtelek Karst is adjacent to the covered karst area. The gravel covered hilly landscape, which is fragmented by erosional and derasional valleys, is drained by the tributaries of Sajó. A 300-400 metres high, gravel-covered watershed rises 1-2 kilometres from the karstic range. From its flat crests waters flow on the one hand towards the west, towards the tributary valleys of Sajó Valley and on the other towards the karst area, where they disappear in edge sinkholes. The water of these sinkholes reappears in Jósva Stream and flows into Bódva Stream. All surface streams between the edge polje of Hosszúszó and the sinkhole of Béke Cave in Nagy Valley enter sinkholes and go through the underground karst system. Under the tops of Aggtelek Plateau the sinking stream system of Baradla-Domica conducts the waters to Jósva springs. The most distant swallet of the spring is the Ördög Hole 343 metres above sea level. The temporary stream originating at the southern edge of Silica Plateau disappears in the large opening of a sinkhole at the limestone bed of Aggtelek Plateau. Here begin the paths of the underground Styx Brook that formed the main passage of Domica Cave by its corrosive and erosive activities. The underground stream is enriched by the waters coming from the other sinkholes situated on the edge of the karst plateau.

Water bodies accumulating under Baradla Top are from a 7 km^2 area. The three most mature sinkholes open up here: the Bába Hole, the Acheron and the Little Baradla swallets. Bába Hole was formed at the confluence of the longest valley having the highest water transport capacity. Tracing tests showed that water from this sinkhole flows via the Long Lower Baradla Cave and appears in one of the Jósva springs, in Medence Spring (Szilágyi 1982). A 1 metre high watershed is situated between Bába Hole and Acheron Sinkhole and therefore water goes to the Acheron Sinkhole during floods. This nourishes the Acheron Brook of Baradla Cave that flows into the Styx at the labyrinth of the Aggtelek entrance area. As the Acheron Sinkhole is not able to swallow large amounts of water,

water runs toward Little Baradla sinkhole which is capable of draining it. These three sinkholes together with the Slovakian Ördög Hole provide most of the water supply of Baradla Cave. Zsombor Hole belongs to the system Lower Baradla Cave. However, it feeds the Lower Baradla Cave at low water level while at times of high water level water flowing into Zsombor Hole also goes to Vörös Branch, which is a side branch of Retek Branch.

The confluent Styx and Acheron Streams no longer flow through the main passages of Baradla Cave, as the level of springs has moved deeper. The stream does not get further than Vaskapu Strait at low and middle water, since water departs to the mainly unknown passages of Lower Caves by different sinkholes (Szilágyi 1982). Nowadays, water runs through the middle level of the cave and reaches the main sinkhole only when high floods occur. Runoff water disappearing in the swallets inside the cave appears in Jósva springs that consist of three independent springs: Táró, Cső and Medence springs. Sinkholes of the Long Lower Baradla Cave constantly provide water to the Lower Cave which appears later on in the Medence Spring. This water originates from the infiltration water of the sinkholes, seepage karst water, groundwater and water from deep reservoirs. The water supply of the Short Lower Cave comes from the large sinkhole situated in the Giant's Hall and reaches the surface at the Táró Spring. The above mentioned two springs are next to each other and were separated from each other by the construction of engineering structures after the great flood in 1955. Although both springs indicate flooding within a few hours, flood reaches the springs at different times (Szilágyi 1982). Side passages join to the main level passage of Baradla Cave that has been continuously developing since the beginning of the Pleistocene (Vid 1988). The hydrogeological system of Domica-Baradla also includes Nagy-Ravasz Hole.

3.1. The hydrological features of Jósva springs

Jósva springs are a group of three springs that are located very close to each other. Medence Spring has the highest discharge whereas Cső Spring is characterized by the lowest level of water flow. The water of these springs originates from the Long Lower Cave while the Táró Spring is fed by the Short Lower Cave. The water regime of the latter spring is characterized by extreme changes. These springs are classic examples of shallow karst springs that are supplied by precipitation. As the residence time of water is very low, it shortly appears on the surface. The quality and quantity of water at the springs fluctuates significantly reflecting the changes of precipitation. The hydrological cycle of Jósva springs is characterized by floods occurring at the end of winter, early spring, spring and early summer (Fig. 1). As a result, the chemical parameters of water fluctuate immoderately, as well (Table 1).

Table 1 Physicochemical parameters of Jósva springs between 2000 and 2001

Date	°C	pH	T.C	Alk.	K	Ca	Mg	Fe	Mn	NH_4	Cl	SO_4	HCO_3	NO_3	NO_2
04.04.2000	10.6	7.21	174	6.0	1.9	110.0	8.7	0.04	0.02	0.31	6.5	18.2	366	4.8	0.01
06.15.2000	11.7	7.70	202	6.7	1.0	129.0	11.2	0.04	0.02	0.07	*11.5*	18.9	409	*7.5*	0.01
08.09.2000	12.1	7.96	197	6.8	1.0	133.0	7.6	*0.38*	0.36	0.01	*11.5*	19.1	412	4.8	0.01
10.02.2000	14.1	7.22	174	5.8	1.7	108.0	11.0	0.04	0.02	0.02	7.5	19.2	354	*11.1*	0.01
12.13.2000	13.2	7.82	165	5.6	1.9	99.4	12.6	0.05	0.02	0.11	10.0	19.2	343	*11.2*	0.01
02.05.2001	11.7	7.47	175	5.9	2.0	116.0	7.2	0.04	0.00	0.01	6.5	38.4	357	*8.4*	0.01
04.17.2001	12.2	7.29	191	6.1	1.8	124.0	7.7	0.06	0.00	0.00	7.5	36.0	372	*7.9*	0.01
06.11.2001	13.7	7.60	193	6.0	1.9	113.0	15.2	0.00	0.00	0.17	7.0	36.0	366	*10.3*	0.01
08.06.2001	13.1	7.62	185	6.2	1.9	103.0	18.1	0.00	0.00	0.15	*10.0*	24.0	378	*11.4*	0.01
10.04.2001	14.3	7.29	186	5.9	1.9	106.0	16.5	*0.12*	0.29	0.32	7.5	16.8	357	*12.1*	0.02
12.10.2001	12.5	7.70	171	5.8	1.7	105.0	10.4	*0.11*	0.07	0.04	9.0	16.8	354	*14.1*	0.00

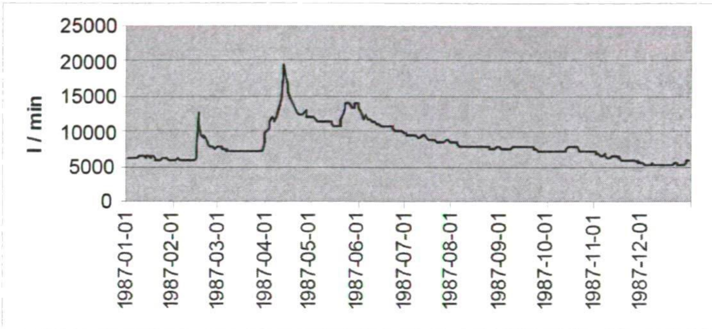

Fig. 1 The changes of discharge of Jósva springs in 1987 (VITUKI)

Table 2 Average annual precipitation on the catchment area of Baradla Cave for 10 years

Weather Station	Mesurement frequency	Multi-annual rainfall (mm)
Aggtelek	daily	701.00
Bagolyvágás	monthly	631.00
Nagy Valley	monthly	578.00
Jósvafő	daily	657.00
Total Average		641.75

In Baradla Cave the Long Lower Cave and the Short Lower Cave take the most of the water. The average discharge of Táró Spring is 300 l/min, however the estimated discharge can reach 1 000 000 l/min in case of floods. The joint discharge of Cső and Medence springs is approximately 10 000 l/min while it rises to 200 000 l/min when floods occur. Owing to the fact that the springs are too close to each other their water flow measurement could not be solved separately and therefore the total discharge was recorded. The multi-annual discharge of Jósva springs is 14 364 m^3/d.

The total annual discharge of the karst springs is equivalent to the annual infiltration on a karstic area. The same applies to the values of the average multi-annual infiltration. The percentage of average multi-annual infiltration can be calculated by using the average multi-annual water flow and the average multi-annual precipitation.

The sum of the *average multi-annual water flow* ($\overline{Q}$) was determined by multiplying the daily water flow by 365:

$$\overline{Q} = 14\,364 \cdot 365 = 5\,242\,860\,(\mathrm{m}^3) \tag{1}$$

If the *average multi-annual precipitation* ($\overline{C}$) is multiplied by the surface area of the drainage basin we get the average multi-annual precipitation for the catchment area in m^3. The total area of the investigated karstic and non-karstic drainage basins is 29.83km^2 (29 830 000 m^2). The *average multi-annual precipitation* for this catchment area is:

$$\overline{C} = 29\,830\,000 \cdot 0.642 = 19\,150\,860\,(\mathrm{m}^3) \tag{2}$$

where 0.642 is the *average multi-annual rainfall* in metres. In the light of the above the *average multi-annual infiltration* ($\overline{B}$) is calculated as follows:

$$\overline{B} = \frac{14\,364}{0.642 \cdot 29\,830\,000} \cdot 100 = 27.37 \approx 27\% \tag{3}$$

This means that the value of the average multi-annual infiltrating precipitation is 173 mm. The determination of the *average multi-annual surface runoff* is required for the above. By establishing a runoff register parcel at Jósvafő weather station we found that surface runoff occurs only in case of heavy rainfalls. Due to their scarcity, the average multi-annual surface runoff usually does not exceed the 2% of precipitation. Since the average slope of the experimental plot corresponds to the average slope of the catchment area, the calculated value is acceptable for the drainage basin of Baradla Cave.

As a result, it can be concluded that the level of the *average multi-annual evapotranspiration* is the 71% of the average multi-annual rainfall (456 mm) in case of 27% infiltration and 2% surface runoff (Table 3). This result matches the outcome of water balance calculations done for both the other areas of Aggtelek Karst, and the karstic area as a whole.

Table 3 The water balance of the catchment area belonging to Baradla Cave

Average multi-annual							
Total precipitation		Infiltration		Surface runoff		Evapotranspiration	
mm	%	mm	%	mm	%	mm	%
642	100	173	27	13	2	456	71

3.2. The analyses of seepage water in Baradla Cave

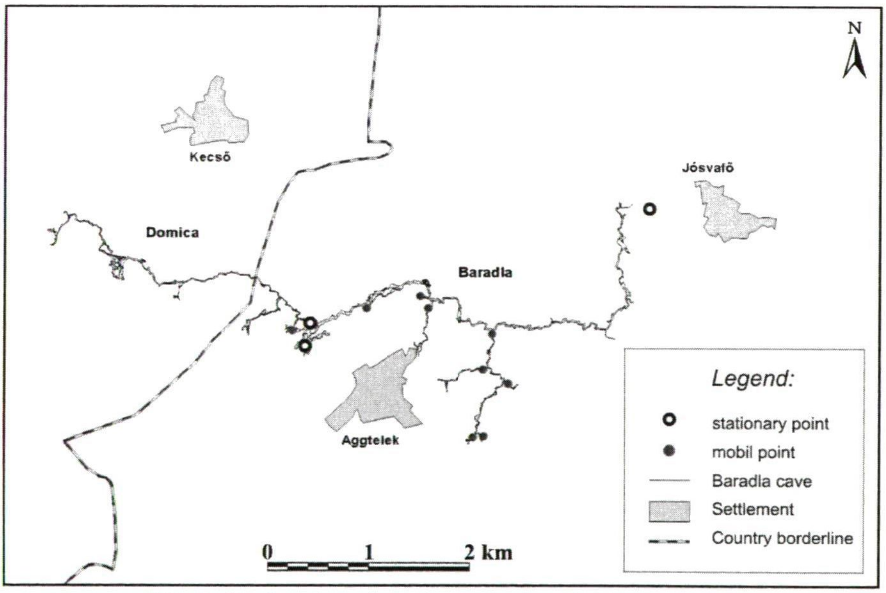

Fig. 2 The location of monitoring stations in Baradla Cave

The water quality of infiltration water is significantly modified by the human intervention and by the vegetation and soil cover of the karst area. As the soil and vegetation cover binds certain substances (e.g. heavy metals) it can change the quality of infiltration water. Seepage water flows directly into the system and therefore can bring harmful substances to the aquifer that restricts the use of the spring as public drinking water supply. A number of researches have dealt with the chemical and hydrological analysis of the cave and the springs (Dudich 1930, Kessler 1955, Jakucs 1960, Sásdi 1992, Stieber 1995, Maucha 1998, Szőke and Keveiné Bárány 2003, Gruber 2004, Gruber 2006). These studies have shown that sometimes contaminants get into the system, which deteriorate its water quality (Szőke and Keveiné Bárány 2003). Consequently, regular monitoring is required. Measurement points were installed in the spring zone in order to study the accumulation and elimination of the various contaminants. Continuous monitoring immediately filters contaminants (e.g. agricultural pollutants) after the onset of flooding. Mobile measurement points had to be installed in order to find the sources of additional pollution (Fig. 2).

Changes in the water chemistry of Acheron Stream linked to the typical regime of the cave are different concerning stagnant flow, slow water flow and sudden flooding (Figs. 3-6).

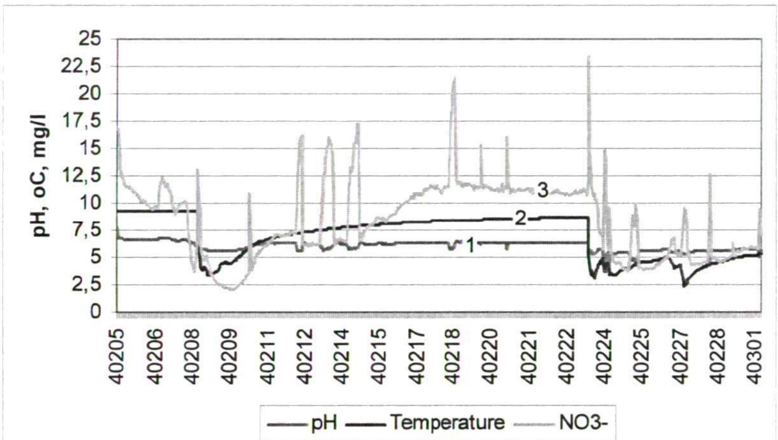

Fig. 3 Acheron Stream, slow melting of snow (February 2004)
1 = pH; 2 = temperature; 3 = $N0_3^-$

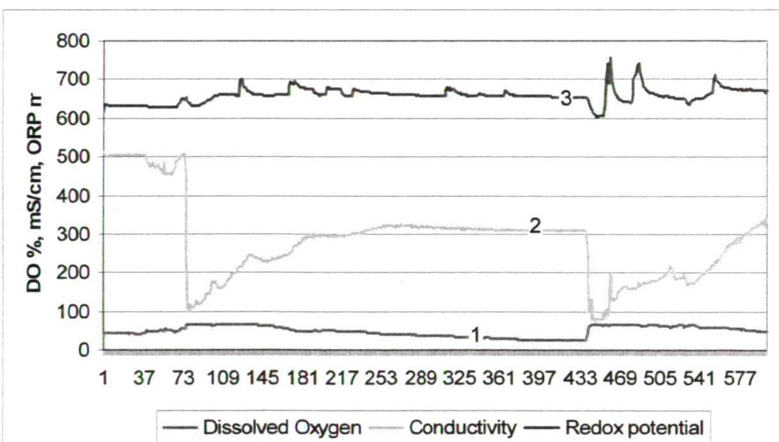

Fig. 4 Acheron Stream, slow melting of snow (February 2004)
1 = dissolved oxygen; 2 = conductivity; 3 = redox potential

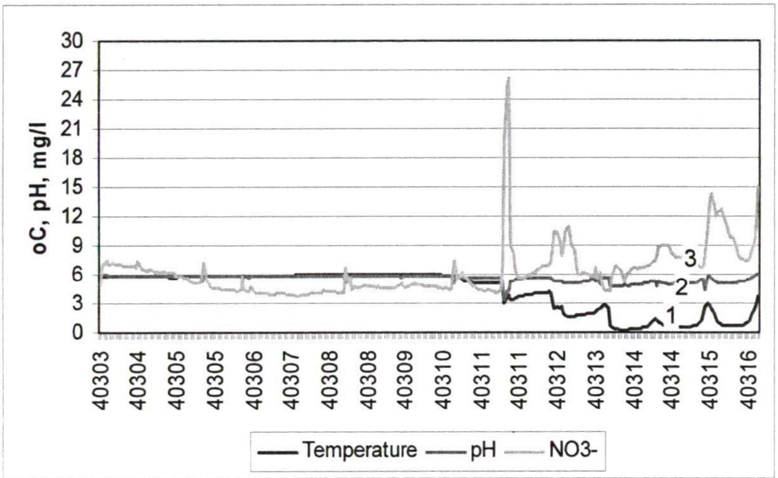

Fig. 5 Acheron Stream, flooding after sudden snowmelt (March 2004)
1 = pH; 2 = temperature; 3 = NO_3^-

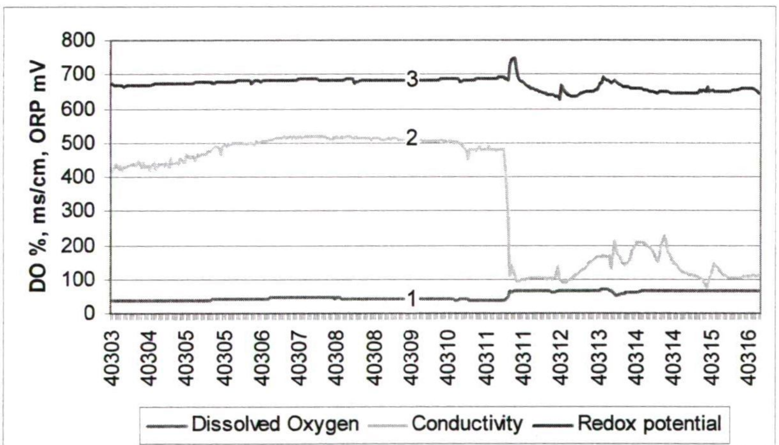

Fig. 6 Acheron Stream, slow melting of snow (March 2004)
1 = dissolved oxygen; 2 = conductivity; 3 = redox potential

As a result of snowmelts due to the rise in air temperature flood waves go through the creek with daily intensity. After the start of snowmelt the dissolved oxygen content of water rises immediately with the first shockwave. Electric conductivity, which usually changes similarly to water temperature, drops suddenly in case of floods. At the time of intense inflow, pH decreases suddenly sometimes even with a two-value-change. Although redox potential increases first, it decreases equally sharply when the intensive inflow stops. The nitrate content of the water rises significantly when infiltration starts and decreases gradually later on. When the amount of inflow lessens a progressive warning of the stream begins. As the flow ceases lakes form in pool-like depressions. Water temperature becomes constant at around 8.8°C. The dissolved oxygen content of water stagnates first and then starts to decrease slowly. pH stabilizes around 7.8 with small fluctuations. Redox potential rises a little bit while the electric conductivity declines. Nitrate concentration steadily decreases due to the different chemical reactions.

3.3. Drip waters

The first drip water samples were collected in January 2009 (Table 4) as a number of dripping points became active after the start of snowmelt. Drip waters were grouped on the basis of their temperature as follows: 8-9°C, 9-10°C and above 10°C. In the case of the first group the solution did not warm up, since the infiltration of rainwater was relatively fast due to the smaller thickness of the host rock and its tectonic features. The second group consists of water with normal infiltration conditions and the ones with extremely low infiltration conditions belong to the third one.

Table 4 Chemical parameters of drip waters (January 2009)

Place	Temp. (°C)	Conductivity (mS/cm^2)	Dissolved ox. (%)	pH	Redox. pot. (mV)	NO_3 (mg/l)
1. Pitvar	10.09	246.0	21.0	9.530	20.10	0.095
2. Acheron room.	9.58	244.0	38.5	9.550	29.40	0.551
3. Róka branch 1	9.80	269.0	10.4	9.450	8.70	0.115
4. Róka branch 2	9.82	287.7	40.5	9.240	117.40	0.014
5. Róka branch 3	9.91	295.9	39.0	9.020	191.10	0.512
6. Kerülő	9.65	289.1	7.2	9.270	94.50	0.155
7. Fekete room.	10.20	285.4	1.1	9.240	66.10	0.025
8. Denevér 1	10.28	294.2	2.8	9.225	72.20	0.655
9. Denevér 2	10.72	339.2	3.8	9.240	76.10	0.547
10. Fekete-t.	10.37	300.1	23.0	10.190	90.10	0.698
11. Danca	11.04	309.2	3.5	9.520	88.60	0.547
12. Törökfürdő	8.66	209.6	17.8	9.480	85.20	0.254
13. Lelák	8.65	210.6	20.6	9.480	86.60	0.965
14. Viasz-u.	9.20	309.8	28.2	9.320	90.30	0.589
15. Morea	9.88	342.0	28.7	9.200	98.30	0.547
16. Gát	9.76	319.0	9.6	9.390	56.70	0.855
17. Csipke-t.	0.70	271.2	46.3	8.980	48.70	0.559
18. Libanon	9.85	220.7	13.7	9.240	88.70	0.115
19. Nehéz-út	9.74	398.5	5.8	9.010	106.10	0.556
20. Vaskapu	9.24	305.1	24.9	9.120	108.40	0.225
21. Törökmecset	9.37	297.0	6.5	9.080	187.10	0.654
22. Szemiramisz	9.28	323.7	39.2	9.160	147.10	0.569
23. 2350 m	9.27	347.1	5.5	8.950	142.90	0.478
24. Matyórojt	9.31	232.6	61.2	9.190	130.40	0.522
25. Csikóstanya	9.35	328.5	13.6	9.010	128.20	0.125
26. Dareiosz	9.30	243.7	46.3	9.120	88.54	0.154
27. Retek branch	8.40	102.4	13.9	9.120	94.40	0.569
28. Anyósnyelv	8.15	270.2	21.7	8.940	107.10	0,488
29. Minerva	9.32	304.6	57.7	8.850	116.20	0.965
28. 4500 m	9.15	275.4	73.6	8.950	116.70	0.441
29. 4600 m	8.82	309.1	44.0	8.850	125.10	0.468
30. 4700 m	8.70	354.4	21.4	8.640	147.10	0.977
31. Vörös Lake	9.24	345.2	25.1	8.750	147.30	0.425

Besides, other chemical parameters were also analysed (Table 4). The redox potential, the electric conductivity and the nitrate concentration of drip waters were lower in January than in April (Table 5) while the pH values and the dissolved oxygen content of the water changed reversely. It means that waters infiltrating after the melting of snow bring more inorganic material into the system and thus the specific electric conductivity rises significantly. While concerning Jósva springs some waters were found to be above the tolerable limit of clean water for $N0_3^-$, dripping water samples never exceeded this limit. pH values differed significantly as the pH of Jósva springs were one order of magnitude lower than the pH of dripping water samples. The changes of pH, redox potential and nitrate concentration imply the attenuation of infiltration water. It can also be concluded that contaminations reach the system mostly due to rapid floods.

Table 5 Chemical parameters of drip water (April 2009)

Place	Temp. (°C)	Conductivity (mS/cm^2)	Dissolved ox. (%)	pH	Redox. pot. (mV)	NO_3 (mg/l)
1. Pitvar	10.04	754	13.90	8.54	188.2	1.563
2. Acheron room	10.58	749	26.25	8.65	175.4	1.554
3. Mórea	10.48	757	1.40	8.54	185.5	3.565
4. Libanon	9.45	978	7.60	8.94	193.2	2.264
5. Vaskapu	10.04	965	9.90	8.34	195.9	1.025
6. Törökmecset	9.39	712	11.20	8.09	192.7	1.463
7. Matyórojt	9.86	932	16.90	8.08	196.4	1.745
8. Csikóstanya	9.75	942	15.90	8.94	207.6	1.519
9. Dareiosz	9.24	549	22.90	8.11	194.2	1.375
10. Retek branch	8.97	1078	14.00	8.96	206.9	2.841
11. Anyósnyelv	8.62	894	18.50	8.21	202.9	1.446
12. Minerva	9.67	1033	18.30	8.02	206.2	2.157
13. 4500 m	9.56	1123	31.20	8.98	208.1	1.111
14. 4600 m	8.62	797	28.30	8.87	203.2	2.381
15. 4700 m	8.85	756	33.40	8.14	202.3	0.740

4. CONCLUSIONS

The water balance for the catchment area of Baradla Cave was determined. It can be concluded that from the average multi-annual precipitation (642 mm) 27% (173 mm) infiltrates into the cave, 2% (13 mm) runs off the surface and 71% (456 mm) enters the atmosphere by evapotranspiration. The hydrogeochemical characteristics of Jósva springs and the dripping waters were analysed separately. The flow rate and the water quality of the springs fluctuate significantly in correspondence with the changes of precipitation. The delay of precipitation is short in the aquifer. The hydrological cycle of Jósva springs is characterized by floods occurring at the end of winter, early spring, spring and early summer.

The infiltration waters of Baradla Cave were listed in three groups based on their temperature. The temperature of these percolation waters were primarily defined by the lithological structure and the thickness of the host rock above. The chemical indicators were evaluated by comparing the samples collected in January and April. Redox potential, nitrate levels and electric conductivity were lower while the pH and the dissolved oxygen content of water was characterized by higher levels in January than in April. This means that waters infiltrating after the melting of snow bring more inorganic material into the system and thus the specific electric conductivity rises significantly. Further monitoring would allow the better understanding of changes in trends and the development of a more accurate drainage basin protection.

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COMPARITIVE EXPERIMENTS OF KARSTIC SOILS ON THE CATCHMENT BASIN OF BÉKE CAVE IN AGGTELEK EXAMINING PARTICULARLY THE RELATIONSHIP BETWEEN THE PHYSICAL QUALITY AND THE METAL CONTENTS OF THE SOILS

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Summary: The paper presents the formation and comparison of the acid and EDTA soluble metal content of the soils collected from the catchment of Béke Cave in Aggtelek. The results show the behaviour of the examined metals in open karstic, and covered karstic areas in soils with different physical qualities.

Key words: metal content, clay, loam

1. INTRODUCTION

Karstic landscapes are sensitive, because the storage water which comes up to the surface provides drinking water. The conservation of this natural resource for the future explains the holistic examination of the influential parameters of the water quality. The soil compound and its physical and chemical features in the karstic area influence mostly the content of the infiltrating water and the processes which occur during the solution in the karstic water system.

The examined area is a catchment of Béke Cave in Aggtelek National Park (Fig. 1), which is divided in two different parts. The northern part is covert open karst covered with rendzina soil on limestone. The southern part is covered by a non-karstic sediment (Miocene/Pliocene sand, clay and pebble), foothill colluvium and forest soils. The two different bedrocks are characterised with different soils.

The aim of the present study is to explore the two soil types, their characteristics, and based on the knowledge gained the interpretation of the distinctness of the karstic processes. The study reveals the physical quality of the karstic soils, and presents their behaviour in terms of the behaviour of certain metals.

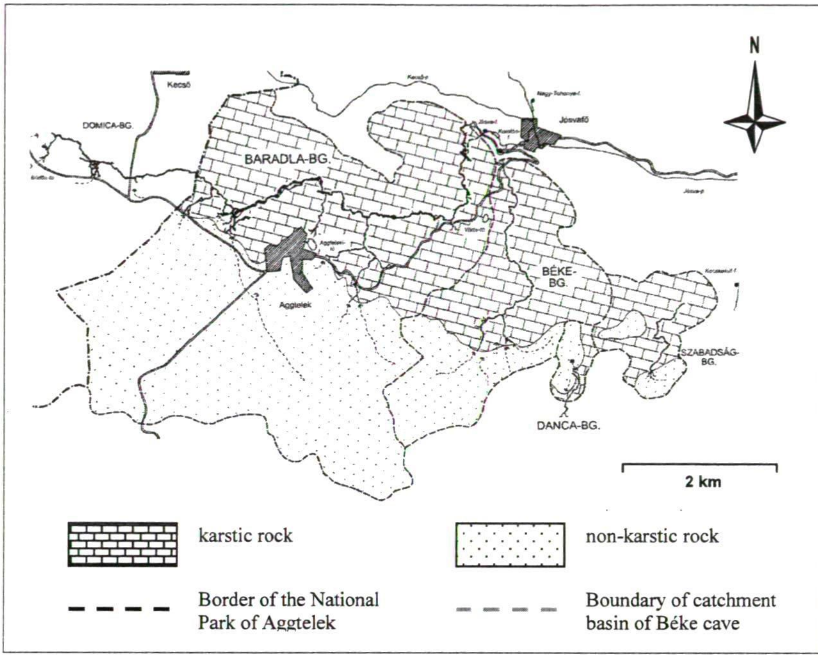

Fig. 1 The geological map of Aggtelek Mountains (Baross 1998)

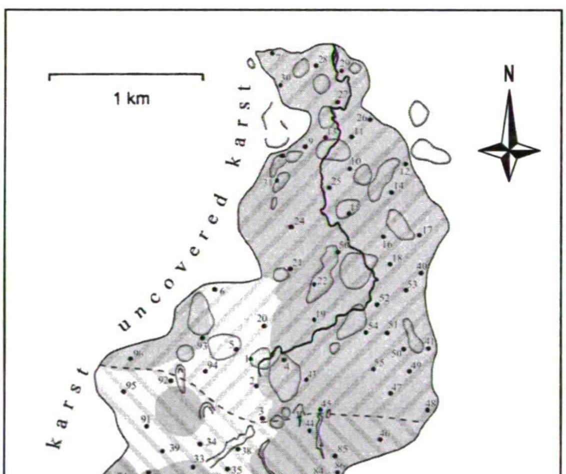

Fig. 2 The infiltration situation and the sampling points of Béke Cave (Zámbó 1986)

2. METHODS

2.1. The position of the study area and its features

The northern part of the catchment basin is uncovered karst, which forms part of the Aggteleki-hegység landscape unit (Aggtelek Mts.). In most areas the bedrock is Middle and Upper Triassic karstic limestone, dolomite, Lower Triassic limestone with Pleistocene pebble intrusions. The typical young break directions of the landscape unit are N-S and NE-SW, which also indicates the direction of the caves. The relief with a broken creased construction is typical of its topographic features, which partly consist of hills, but mostly low mountains of medium height. The geographic structure of the area is rich in transit caves with dry valleys and karstic valleys as well as karstic forms. Red clay is found on the limestone in a lot of places, which influences soil formation. The clayish brown forest soils are formed with the combination of clay-loam on the Pannonian loose sediments and on the Triassic slate (Dövényi 2010).

The southern part of the examined area is covered karst which reaches into the landscape unit called Putnok hills, the surface of which is mostly covered with Pliocene clayish sandy sediments and Pleistocene loam. Triassic limestone formations and Devonian-Carboniferous metamorfits can be found here. Oligocene gritstone and marl intrusions are present in the western and south-western part at the rock basin. The typical features of its relief are: south and south-eastern flow hills are fragmented by valleys. Some 20-20% of the surface of the landscape unit is occupied by tops, ridges and river floodplains with mostly loose sediments; about 5% is terrace surface and 55% is foothill slope. The surface of the area of the basin in the landscape unit is mostly covered by clay and sand along with Pliocene andesite tuff and loess-like sediments in smaller patches. Most of the soils (82%) are of a clay-loam texture, mostly clayish brown forest soil. Apart from this rendzina soils can be found on the limestones. Chernozems are present in a small area as well as Ramann brown soil and meadow illuvial soil (Dövényi 2010).

2.2. Sampling and methods

We collected soil samples (Fig. 2) from 98 sampling points during the summer of 2003. The soil samples came from two depths: one from the surface (0-10 cm) and the other from 20-30 cm. We determined the pH, organic matter-content, the acid- and EDTA soluble heavy metal content and the particle size distribution of the soils.

The acid soluble heavy metal-content was determined after digestion with an acid mixture (HNO_3-H_2O_2-$HClO_4$) (Rowell 1994).

The EDTA soluble metal content was determined after shaking with 0.02 M EDTA solution (pH=4.65 ± 0.05) and filtering it (Lakanen and Erviö 1971). The manganese, iron, magnesium, calcium, potassium and aluminium content of the vegetation and the soils were determined with ICP-AES techniques, and the copper and zinc with FAAS techniques. The measurements took place at the University of Veszprém.

2.3. Discussion

The texture of the examined soil samples can be classified as clay, clay-loam, and loam. Since the grain size influences the binding of the metals I evaluated the physical classification of identical soils and the metal contents and after that I averaged them. Table 1 shows the metal content of the different soils in different depths.

Table 1 The relationship of texture and metal content on the karstic soils

Acid soluble metal content (mg/kg)	Depth F=near surface A=lower layer	clay	clay-loam	loam
Cu	F	20.19	20.00	14.57
	A	21.18	20.68	13.05
Ni	F	25.16	29.98	15.17
	A	33.01	26.65	14.93
Zn	F	109.66	93.39	109.99
	A	98.15	101.20	87.77
Co	F	9.48	11.64	8.41
	A	12.31	11.46	8.73
Cr	F	40.89	46.66	27.16
	A	53.69	67.18	16.10
Cd (μ/kg)	F	293.36	184.10	153.16
	A	161.11	156.32	85.42
Mn	F	924.31	950.65	1171.14
	A	692.81	867.45	878.87
Fe	F	26394.70	24741.37	17174.90
	A	30143.93	25779.82	17278.52
Al	F	36885.01	39210.33	22143.06
	A	45306.31	37815.40	22834.27

The results show that in the case of copper, zinc and cadmium the values are lower on the deeper level, which indicates that these metals are accumulated near the surface layer, less mobile in the other. Of course, the pH value plays a considerable role in the establishment of this tendency. At the same time it may signal the vegetation uptake in the root zone of the plants (on the deeper levels) or leaking into the system may cause this tendency.

We examined the changes of the acid soluble metal content with depth in soils with different texture.

Higher concentration of copper can measured in clay and clay-loam soils in both depths. The copper content is nearly similar in the two soil fractions. The concentration is the lowest in loam soils in both depths. The copper concentration of loam soils decreases with depth, while in the case of the clay-loam it does not change significantly. Small-scale rise can be observed only on clay soils.

The nickel content of the soils is the highest in the near-the-surface samples in clay-loam. The highest concentration is from the deeper level samples in the clay soils. In both depths the nickel concentration is the lowest in the loamy soils. In the loam and in clay-loam soils it decreases on a small-scale with depth, while in the case of clay growth can be experienced in the nickel concentration.

The zinc content in the surface clay and loamy soils is almost identical; on the other hand it is the lowest in clay-loam soils. Opposite to this the highest concentration is measurable in the lower level in clay-loam soils; the zinc concentration is lowest in the case of loam soils. With depth the decrease of concentration (of zinc level) is experienced in clay and loam soils, and in the case of clay-loam soils an increase is experienced.

The cobalt concentration in the upper level in clay-loam soils is the highest one, while the deep samples of clayish soils show the highest value. In two depths the lowest concentration is measured in the loam soils. With depth increase can be observed in the case of clay soils, while no considerable difference can be observed in the other two soil types.

At the time of the examination the chromium content of the soils in both depths is the highest in clay-loam and the lowest concentration is found in loam soils. With depth there is a concentration decrease in loam soil and increase can be observed in clay and clay-loam soils.

The cadmium content of the soils in both depths is highest in the clay samples, the lowest in the loam soils. With depth a decrease can be experienced in all three soil texture types.

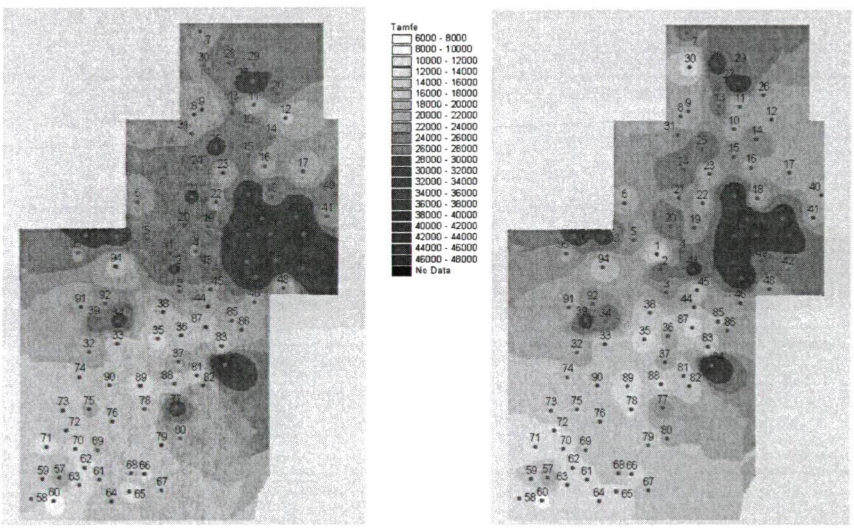

Fig. 3 Distribution of the acid soluble iron in lower and the surface layers in the study area (the presented surface is the result of an IDW interpolation, carried out for a better visualization of the results)

It can be verified that the manganese concentration shows the highest values in loam soil both in surface samples and deep samples. We measured the lowest concentrations in the clayish soils. With depth an obvious decrease can be observed in all three soils.

In the case of the iron content the highest concentration can be measured in clay soils in both depths and the lowest concentration in loam soils (Fig. 3). With depth the clay and clay-loam soils show considerable, while the loamy soils a small-scale increase.

The concentration of the aluminium examined in the upper layer of the soils shows the highest content in clay-loam soils and the lowest in loamy soils. In the sample originating from the deeper layers the highest concentration can be measured in clay soil while the lowest in the loamy soil. The aluminium concentration is growing in the clay soils with depth whereas it decreases in clay-loam, (at a bigger rate) and in the loamy soils (at a smaller rate).

The two maps in Fig. 3 illustrate clearly that the acid soluble metal content, in the hidden open karstic area covered with soil is higher, and this confirms the statement that the probability is higher for the mobilisation of metals here, and thus the risk of hazard is also higher.

We present the proportion of soluble metal contents of the acid soluble and EDTA soluble metal content regarding different metals, and different soil types (Table 2). The EDTA soluble metals are important, because these may get into the system or the plants soon and may cause damage. Where the EDTA soluble metal content represents a bigger proportion of metals soluble with acid, there is a bigger part available for plants, but they may leak into the mobile heavy metal system, which increases the potential danger of the pollution of the natural, karstic water directly (Zseni 2003).

Table 2 The proportion of EDTA soluble metal content.

Element (%)	Depth F=near the surface A=lower layer	clay	clay-loam	loam
Cu	F	46.0	38.2	64.4
	A	38.0	40.7	79.0
Ni	F	8.9	7.5	12.4
	A	5.4	7.9	10.4
Zn	F	12.3	15.2	16.8
	A	7.5	10.4	12.3
Co	F	30.7	31.9	20.9
	A	37.8	40.1	21.7
Cr	F	0.2	2.6	1.3
	A	1.3	3.0	1.5
Mn	F	45.7	51.8	31.0
	A	50.7	43.2	21.5
Fe	F	0.9	0.9	1.0
	A	0.5	0.6	0.5
Al	F	0.9	0.7	0.8
	A	0.6	0.6	0.8

Copper is the most mobile in the loam soils, in the lower level of these soils 79% of all the copper content is present in a form which is easily soluble. In the surface soil it is the most mobile in loamy soils, on the other hand it is the least mobile in clay-loam soils. In the lower level the highest value of copper is in the loam soils, the lowest value can be measured in clay soils. In the case of clay it decreases with depth, in the case of loam there is a small-scale increase while in clay-loam stagnating values can be observed.

In the mobile nickel content it can be experienced that in the upper level the lowest value is in clay-loam soil samples, the highest one is shown in the loamy samples. In the lower level the proportion is the lowest in clay-, the highest in loam samples. With depth a decrease in metal content can be experienced in all three types of soil texture.

Zinc is most mobile in the upper samples in clay-loam, in the lower level in the loamy soils. The lowest mobility is in the clay soils in both depths. With depth a decrease in the mobility of zinc can be measured in the case of all three soils.

In all three cases the cobalt content is the lowest in loamy soils, the highest values can be measured in clay-loam samples. With depth it grows in clay and loam soils, and decreases in clay-loam soils.

In the case of chromium there is a very small mobile part, the least in clay soils, the most in clay-loam soils. The mobile chromium content grows in clay soils with the increase of depth, decrease can be observed in the other two soil types.

Manganese is the most mobile in the surface layer in clay-loam soils, in the lower level in the clay soils. It is the least mobile in both depths in loam soils. The mobility increases with depth in clay, it decreases in loam and in clay-loam soils.

The iron shows a value of 1% in the surface samples of all three types of texture. It is the most mobile in the deeper level of clay-loam soils, but it is only 0.5%, and the mobile metal content is equal in clay and loam soils (Fig. 4). With depth a decrease can be observed in the case of all three soils.

Aluminium has the highest mobility in clay among the surface samples; the lowest value is in clay-loam soil. In a deep level sample the proportion of the mobile aluminium content is somewhat higher in loam soil than in clay and clay-loam soils. With depth a decrease can be experienced in case of all three soils.

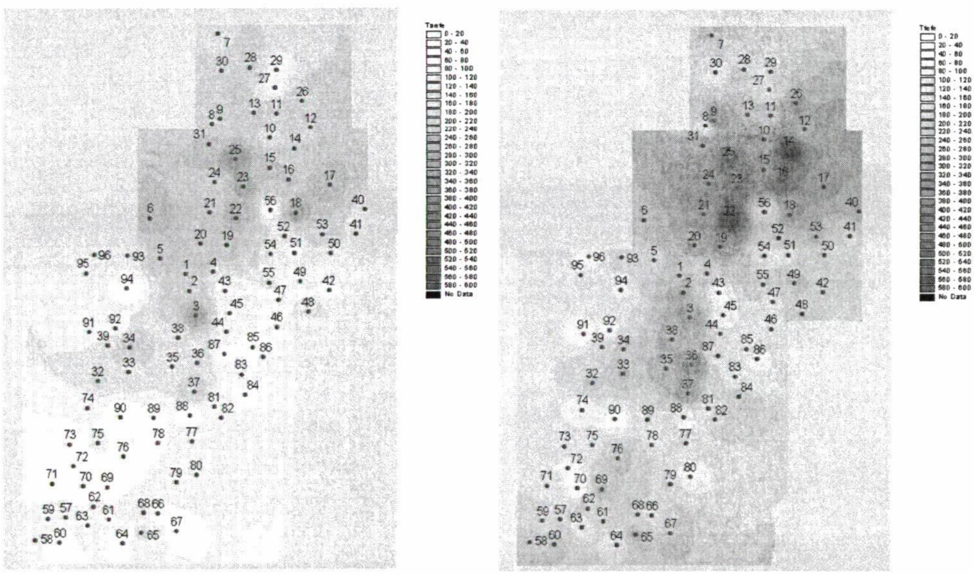

Fig. 4 The maps illustrate the distribution of EDTA soluble iron content in two depths (lower and near surface layers) in the study area.

3. CONCLUSIONS

On karstic soils the filtrations of water (which depend mostly on the soil texture) regulate the motion of metals. To sum up it can be stated that clay lets less water infiltrate, thus metals moving together with water must accumulate in clay. In soils with bigger pore volume the metals move more easily with the water. In karstic areas the motion of the metals is influenced greatly by the infiltrating water and metals can get into the karstic water system, thus plants can uptake them and later they can return it back into the system. This is the reason why it is very important to know the soil dynamics well as opposed to non-karstic areas.

Generally we can state that clay soils bind most of the metals and their concentration increases with depth. In the case of clay-loam and loam soils a lower concentration of metals can be found both in the near-surface layers and in lower levels. This special feature is in connection with the regional distribution of the different-textured soils in the catchment.

In the case of the mobile metal content we can say that copper, nickel and zinc have the highest mobility in the loam soils, while chromium is the most mobile in clay-loam soil. Soil texture has marginal influence on the mobility of iron and aluminium in the soil.

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PRELIMINARY STUDIES OF FRESHWATER TUFA DEPOSITS IN MECSEK MTS., HUNGARY

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Summary: The geochemical and stable isotope analyses of karst springs and their freshwater carbonate deposits provide an opportunity to reconstruct past climate changes. Nevertheless, there are still very few paleoclimate records obtained from freshwater carbonate deposits in Hungary. The present study focuses on five recently depositing freshwater tufa sites (Anyák Spring, Csurgó Spring, Pásztor Spring, Dagonyászó Spring and Kánya Spring) located in Mecsek Mts. (Southern Hungary) as possible sources for Holocene paleoclimate research. Carbonate samples were collected for stable isotope analyses in June and August 2011 and a monitoring programme was started in October 2011. The stable isotope analyses of the rock samples reflect the effect of continentality and suggest strong soil zone CO_2 contribution.

Key words: paleoclimatology, freshwater tufa, stable isotopes, water chemistry, seasonal variation

1. INTRODUCTION

Terrestrial carbonate deposits (travertines, freshwater tufas and speleothems) are of particular importance in paleoclimatological, paleoenvironmental and geological studies. Speleothems, such as stalagmites, stalactites and flowstones, are a rich archive of terrestrial paleoclimate information (e.g. Wang et al. 2001) particularly since they offer the dual advantages of being closely tied to the mean hydrological balance and being a nearly ideal material for high precision U/Th disequilibrium series dating. Recent studies have proved that freshwater carbonate deposits, such as travertines and tufas can also be used in paleoenvironmental reconstruction (Andrews 2006, Lojen et al. 2009, Cremaschi et al. 2010) and their geochemical composition can be correlated with climate records gained from lake sediments, ice-cores (Stuiver et al. 1995) and marine sediments (Imbrie et al. 1984). The effects of global climate changes can be studied on them, since these deposits reflect local paleo-precipitation patterns and preserve key information on the paleoenvironment, as well.

In Hungary, in spite of the existence of large karst areas such studies have been delayed and there are still very few paleoclimate records obtained from terrestrial carbonate deposits (Kele et al. 2006, Kele 2009, Siklósy et al. 2009). Small freshwater tufa sites are common in Mecsek Mountains and their sampling is easily achievable. As tufas are laminated, long-term monitoring of water parameters is the best way to study the characteristics of their deposition and the way how they preserve climate signals. This paper presents the main freshwater tufa depositing streams chosen for a paleoclimate reconstruction and the preliminary results of our monthly observations.

2. MATERIALS AND METHODS

2.1. The study site

The tufa-bearing streams are located in Western and Eastern Mecsek. The geological structure of Western Mecsek is characterized by an anticline with an eastern-western line of strike. The rocks of the anticline are particularly stressed, fragmented and moved by faults (Barta and Tarnai, 1999). In Western Mecsek karstic rocks geologically belong to one single block, however, on the surface they can be found in three different zones. Three of the studied objects, Anyák (Anyák-kútja), Dagonyászó and Kánya springs, are located on the largest karstic block (Fig. 1). The area is built up by well-karstifiable, Triassic rocks (Lapisi Limestone Formation, Zuhányai Limestone Formation, Csukma Dolomite Formation) in which numerous small caves, dolines and karst springs were formed. The karstic rocks of Eastern Mecsek are of Jurassic origin and have less suitable petrographic characteristics for karstification and speleogenesis. Two springs sites, Csurgó and Pásztor springs, have been investigated here (Fig. 2).

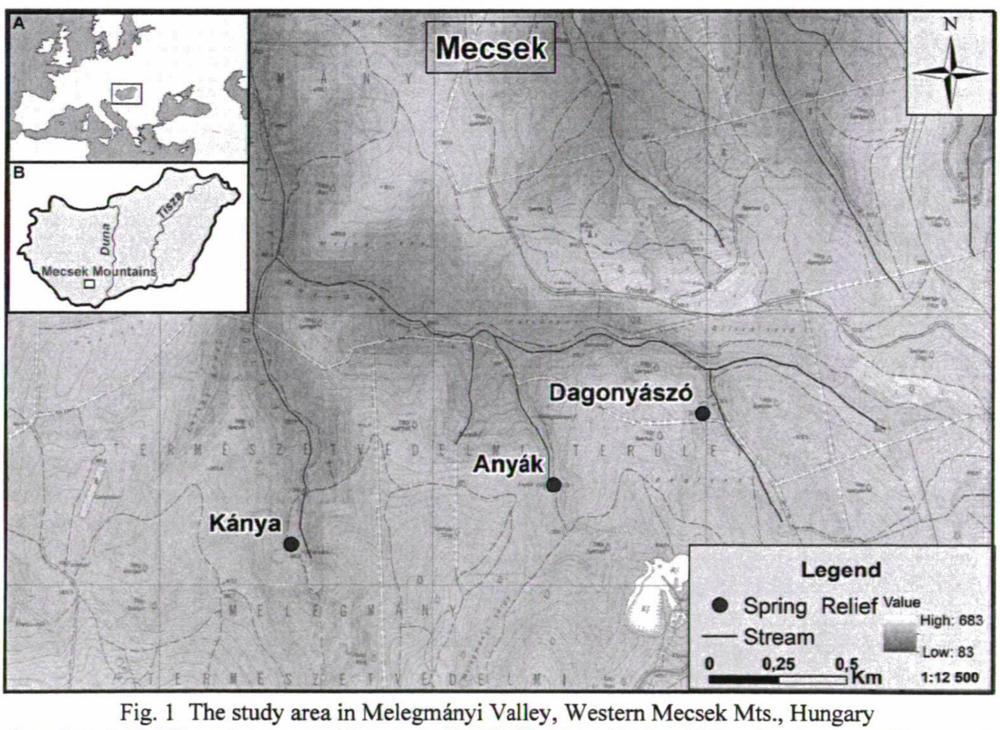

Fig. 1 The study area in Melegmányi Valley, Western Mecsek Mts., Hungary (based on 1:10,000 scale topographic map in EOTR (Uniform National Mapping System of Hungary)

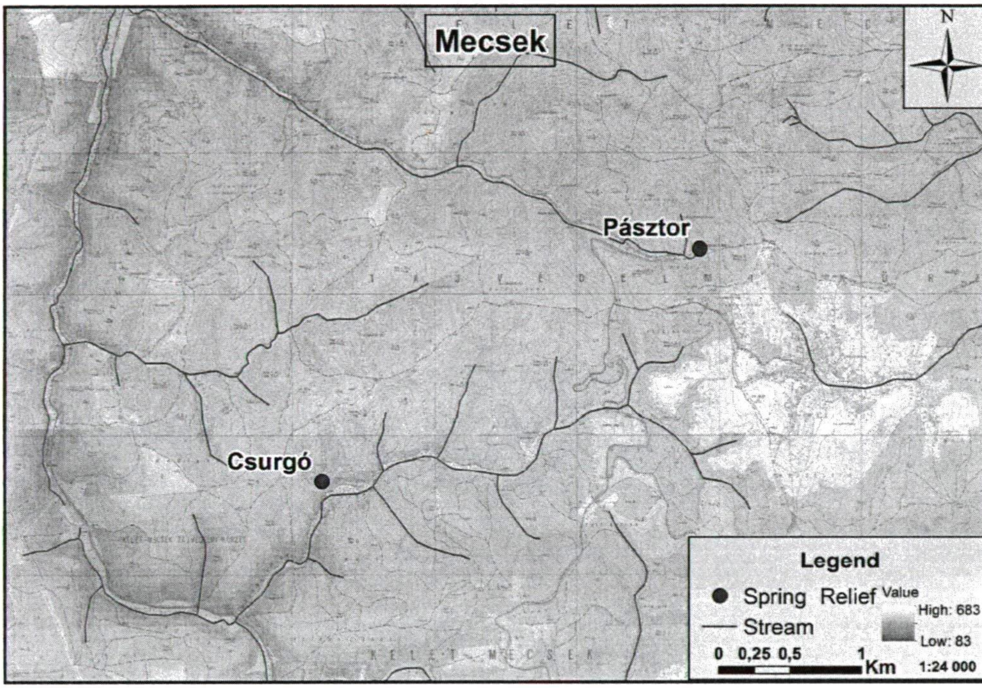

Fig. 2 The study area in Eastern Mecsek Mts., Hungary (based on 1:10,000 scale topographic map in EOTR (Uniform National Mapping System of Hungary)

2.2. Methods

Monthly observations have been carried out for 10 months since October 2011. Two measurement points were set at each spring sites where the basic physicochemical parameters of water (pH, conductivity, temperature) were measured *in situ* on a regular basis by using a WTW device. Water samples were collected in 100 ml bottles for determining alkalinity which were analysed within 48 hours by acid-based titration with 0.1 M HCl. Two meteorological parameters (air temperature and relative humidity) were also recorded at each measurement points.

Recently deposited carbonate samples were collected for stable isotope ($\delta^{18}O$, $\delta^{13}C$) analyses in June and August 2011 at 10 spring sites. The stable isotope analyses were performed at the Institute of Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Budapest, Hungary. Oxygen and carbon isotopes of bulk carbonate were determined using a Finnigan delta plus XP mass spectrometer. Isotopic compositions are expressed in the traditional δ notation in parts per thousands (‰) relative to PDB ($\delta^{18}O$, $\delta^{13}C$). Reproducibilities are better than ±0.2 ‰ for the $\delta^{18}O$ and $\delta^{13}C$ values of carbonates.

3. RESULTS AND DISCUSSION

3.1. The tufa sites

The tufa depositing streams in Mecsek Mountains are usually small creeks having water discharge ranging from 0.02 to 1.4 l/sec. The first tufas usually appear 10-80 m from the spring site and form along the streams until the water loses its ability to deposit freshwater carbonates. In all cases water flows along a single course from the spring at the observed parts, however due to the changes of water flow rate and evaporation, some parts can dry out during the warm season. During summer the surfaces of the tufas are covered by moss, algae and cyanobacteria (Fig. 3).

Fig. 3 Moss and algae cover the freshwater mini waterfall of Anyák Spring, May 2012

The karst water of Anyák Spring (Anyák-kútja) deposits the largest freshwater tufa dams in Mecsek Mts. However, the first fluvial crusts appear 20 m from the beheading of the spring, the largest dams are to be found 200 m further. The deposition rate becomes higher due to changes of surface morphology, and therefore a series of dams and cascades were formed on steep stream bed. Kraft et al. (1986) suggests that the thickness of the dams is about 8 m. The height of the deposits sometimes exceeds 1-1.5 m. The limestone fills the complete cross section of the narrow valley.

Kánya and Mariska springs are located in Nagy-Mély Valley and have a 400 m long riverine tufa deposition along the valley. The first tufa deposits appear approximately 10-15 metres from Kánya Spring before the water of Mariska springs flows into the stream. A series of smaller and larger dams can be found along the riverbed for 400 m owing to the continuous outgassing of CO_2 (Fig. 4).

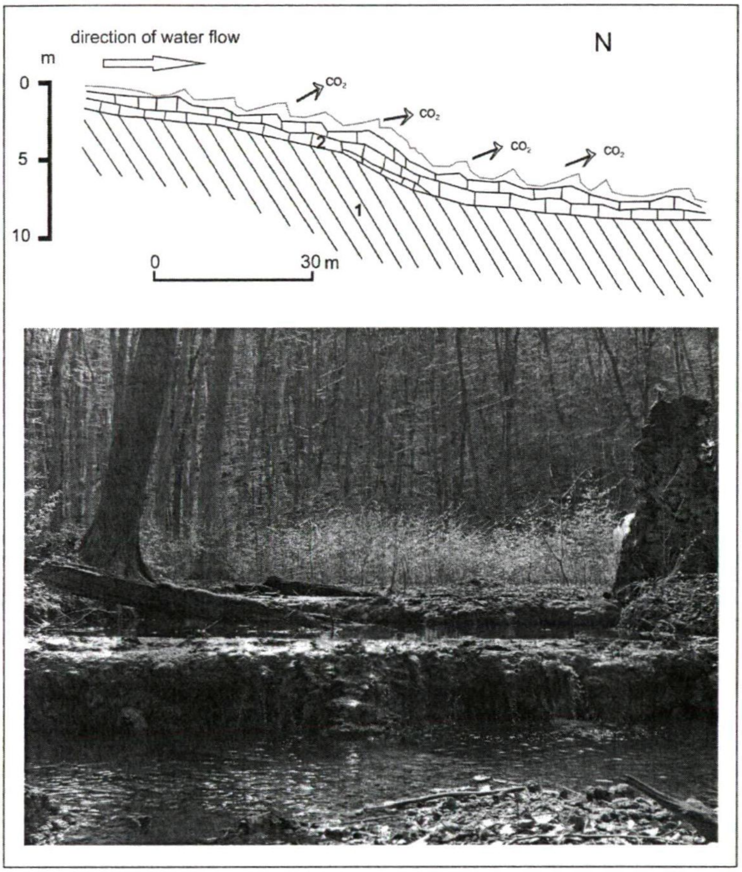

Fig. 4 Tufa dam deposition at Kánya Spring as a consequence of continuous CO_2 degassing.
1: bedrock 2: recently depositing freshwater tufa

The fan-shaped tufa deposits at Dagonyászó Spring are quite porous and contain a high amount of organic material. The first deposits are little (0.1 m high) waterfalls forming 15-20 metres far from the spring.

Csurgó Spring is one of the most well-known sites in Eastern Mecsek. The spring has no specific vent; the water simply appears in the stream bed. Several mini-dams and two large cascades make the site spectacular. Unfortunately, the freshwater tufa cascades were destroyed by falling trees during a storm in July 2012.

Pásztor Spring is the uppermost spring of Vár Valley. Some small sinkholes are known on its catchment area (Karft and Scheuer 1988). The supersaturated water led to the formation of both a fan-shaped valley floor infilling and several larger tufa dams. Freshwater tufas are quite consistent.

3.2. Physicochemical water parameters

Water temperature shows a regular seasonal pattern reflecting the variation in air temperature, being higher in summer and lower in winter. Due to the moderating effect of the karst aquifer the amplitude of changes were 4.6°C, 4.0°C, 3.8°C, 3.0°C and 2.9°C at

Csurgó Spring, Pásztor Spring, Anyák Spring, Kánya Spring and Dagonyászó Spring, respectively. The reason behind this high amplitude in the case of Csurgó Spring is that there is no specific spring source, water appears in the stream bed and consequently it starts to equilibrate with surface temperature. The highest temperatures were recorded in April and July and the lowest in October and January. Downstream the water temperature increased in summer and decreased in winter. The seasonal amplitude rose to 14.5 °C, 18.1 °C, 19.1 °C, 8.9 °C and 7.8 °C, respectively.

Alkalinity had a similar seasonal pattern as water temperature. It was higher from late spring to autumn and lower from winter early spring (Fig 5.). Similarly to electric conductivity, alkalinity decreased downstream which is most probably due to tufa deposition. The highest values of electric conductivity were measured at Anyák and Kánya springs (655-766 μS/cm and 702-755 μS/cm, respectively), while Pásztor Spring was usually characterised by much lower values (570-680 μS/cm). This is due to the differing quality of the limestone aquifer. Similarly low values were recorded at other springs in Vár Valley and in Óbánya Valley.

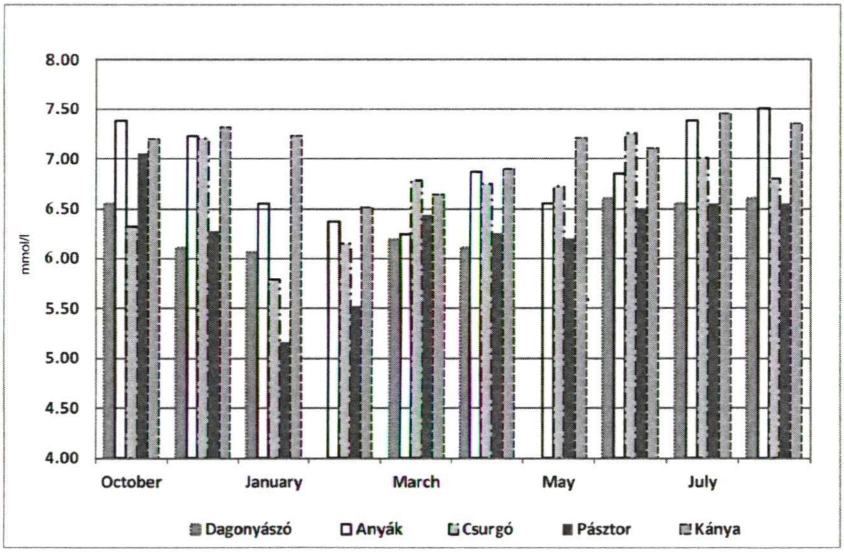

Fig. 5 Variation of alkalinity at the springs, 2011-2012

Contrary to electric conductivity and alkalinity, pH values gradually increase downstream. According to the scientific literature (Kano et al. 1999) the seasonal variation of pH is characterized by high winter and low summer values, since more uptake of soil-originated CO_2 intensifies the dissolution of $CaCO_3$ and reduces the pH of the water. Soil pCO_2 is the highest from July to September and changes of the Ca^{2+} content, alkalinity and pH usually follow its seasonal variation with a delay of 1 or 2 months (Kano et al. 1999). The highest pH levels were measured at the end of November and a second peak was observed at the end of January. Except for Pásztor and Kánya springs pH values slightly increased at the beginning of summer (Fig. 6) and decreased in August. Usually, Anyák and Kánya springs are characterized by higher pH levels than the other springs, most likely owing to differing aquifer conditions.

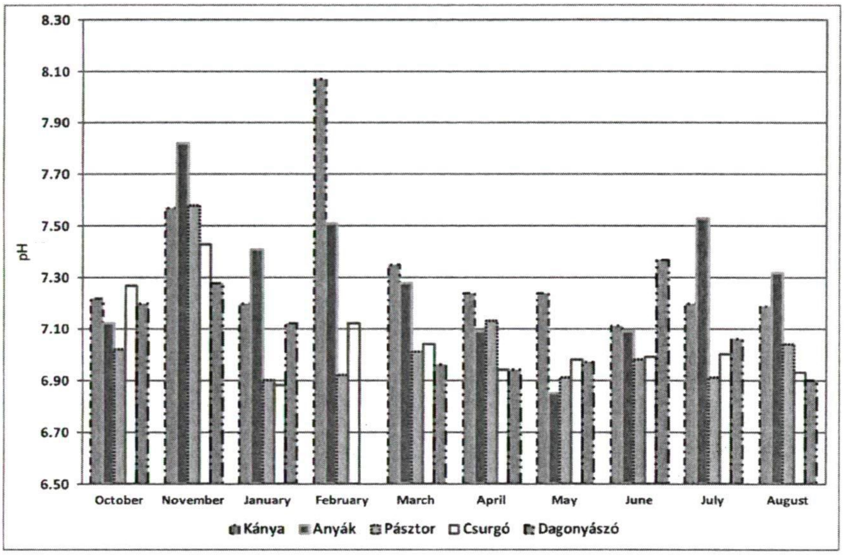

Fig. 6 Monthly changes of pH, 2011-2012

3.3. Correlation coefficients between the variables and the different springs

Alkalinity, electric conductivity, pH, water temperature and air temperature were analysed. Air temperature was recorded at each measurement sites when the physicochemical parameters of water were measured. Large correlation coefficients were found between water temperature and air temperature with a correlation coefficient R^2=0.463 on a 0.01 significance level. At the tufa depositions a negative correlation was experienced between water temperature and alkalinity (R^2= -0.475) which is most probably due to the temperature dependence of dissolved CO_2 and the changes in the amount of available CO_2 during infiltration.

Concerning pH a connection was found between Csurgó and Kánya and between Csurgó and Pásztor springs on a 0.05 significance level. The relationship was even stronger between Kánya and Pásztor springs (R^2=0.855 on a 0.01 significance level). The changes of electric conductivity were similar in case of Anyák and Dagonyászó, Anyák and Kánya, Csurgó and Kánya springs, on a 0.05 significance level. Interestingly, no correlation was found between Dagonyászó and Kánya or Anyák and Csurgó springs. Regarding alkalinity only Anyák and Kánya springs correlated with each other on a 0.05 significance level. This might be due to similar aquifer conditions, however, further research is needed in order to understand the relationship between the observed springs.

3.3. Stable isotopic composition of carbonates

15 rock samples were collected at ten spring sites in the summer of 2011. Table 1 shows the isotopic composition of the tufa samples. The $\delta^{13}C$ values of our tufa samples are isotopically light and range between -9.0 ‰ and -11.6 ‰ (V-PDB) with a mean value of -10.3 ‰, suggesting strong soil-zone CO_2 contribution. Comparing our stable isotope data with the database established by Andrews et al. (1997) and Andrews (2006), the samples

from Mecsek Mountains are similar to the tufas collected in Poland and in the Dinaric Karst concerning $\delta^{18}O$ values, reflecting the effect of continentality compared to the tufas collected from Western-Europe (Fig. 7).

Table 1 The isotopic composition of freshwater tufa samples from Mecsek Mts., Hungary

Tufa-depositing springs	$\delta^{18}O$ ‰ (V-PDB)	$\delta^{13}C$ ‰ (V-PDB)	Altitude (m)
Kánya Spring	-8.6	-9.9	307
	-8.7	-11.2	307
Anyák Spring	-9.3	-9.9	320
	-9.4	-10.1	319
	-9.2	-10.6	318
Pásztor Spring	-9.1	-11.1	430
Tettye Spring	-9.3	-10.7	208
	-9.1	-10.4	208
Zsolnay Spring	-8.6	-10.0	348
Dagonyászó Spring	-9.2	-11.6	321
Mecsek Spring	-8.5	-11.4	310
Bugyogó Spring	-8.7	-9.4	350
Vadvirág Spring	-8.6	-9.0	360
	-8.6	-9.2	360
Csurgó Spring	-8.9	-11.0	320

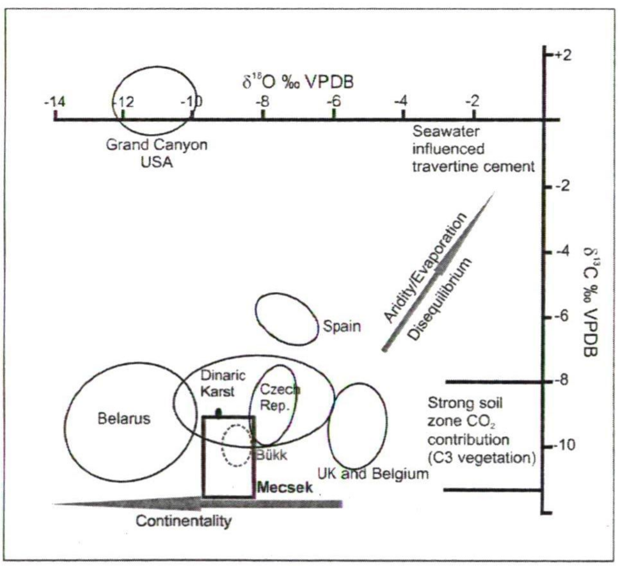

Fig. 7 Isotopic cross plot of freshwater tufa deposits from Mecsek Mts. with other European samples (after Andrews 2006)

4. CONCLUSIONS

During our research we have studied some of the major freshwater tufa depositions of Western and Easter Mecsek Mts., Hungary for 10 months. The seasonal variation of the different physicochemical parameters of water was observed during the monitoring period.

It also became evident that pH increases, while alkalinity and electric conductivity decreases downstream. The variation of water temperature depends on air temperature. Statistically significant relationship was found between water and air temperature and between water temperature and alkalinity. Correlation was discovered between some springs concerning the fluctuation of the various parameters, nevertheless regarding pH and conductivity, significant connection was only found in the case of Kánya and Csurgó springs.

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THE ANALYSIS OF THE CHEMICAL COMPONENTS OF KARST SPRING KÁCS AND SÁLY WITH MULTIVARIANT STATISTICAL METHODS

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Summary: Karstic aquifers are very vulnerable sources of groundwater on the Earth. The karst springs of Kács and Sály are important reservoirs, as they provide drinking water for more than 10 settlements in the north-eastern part of Hungary. I monitored these and six other springs for two years. The aim was to know their function and conditions furthermore their relationships with other karst spring in their neighbourhood. In order to explore the relationship with the different karst springs I used cluster analysis.

Key words: statistical methodology, cluster, discriminant, karst water

1. INTRODUCTION

Drinking water is a treasure. Nowadays it is even more so, when the growing human population has a huge impact on its environment, especially on the water. On the Earth, 25% of the population get their drinking water from karstic aquifers (Ford and Williams 2007). This percentage is expected to rise substantially in the future. The karst is a 3-dimensional ecological system; the effects of both anthropogenic activity and natural phenomena appear very quickly, that's why it is so vulnerable. In addition to karst water quantity, quality is becoming increasingly important.

The karst springs of Kács and Sály are situated at the south-east piedmont of Bükk Mountains between Mezőkövesd and Miskolc. They supply drinking water for 12 settlements in the southern part of Borsod-Abaúj-Zemplén County. This group of springs is very interesting, as their temperature is higher than that of other, natural karst sources of the Bükk Mts. It means that they are not only fed by the infiltrating waters, but also have supply from rising groundwater. The presence of thermal karst at the foreground of Bükk Mts is proved (several thermal baths are well-known, Mezőkövesd-Zsóry, Bogács, Miskolctapolca).

To explore the function of these springs we monitored them and 8 other points for 2 years, with systematic, fortnightly sampling. The chemical composition of the samples was measured in the field and also in laboratory. Hydrochemical analysis not only provides information about water quality, but also insight into the functioning of the karstic aquifers.

I wanted to know if there was a relationship between the water of thermal wells, and sources in the neighbourhood and the water bodies of Kács and Sály. But unfortunately there's no long time series data available, only data measured 1 time. So I chose modern statistical tools to explore the relationships. In hydrology cluster analysis is a common method to analyse the groundwater's chemical properties.

Kács and Sály are situated in the foothills of Bükk Mountain, in the north-eastern part of Hungary. The springs stem in a valley head, in Eocene limestone, at 195-202 m asl. so they can be considered the lowest discharge level in these mountains. The catchment area is located in Southern Bükk, built up mostly of Triassic limestone, which has poor water conductivity ability. Near the Sály spring, there is also a dolomitic formation, that's why this spring has higher magnesium ion content than the others. The situation and the geology of the study area are shown on Fig.1.

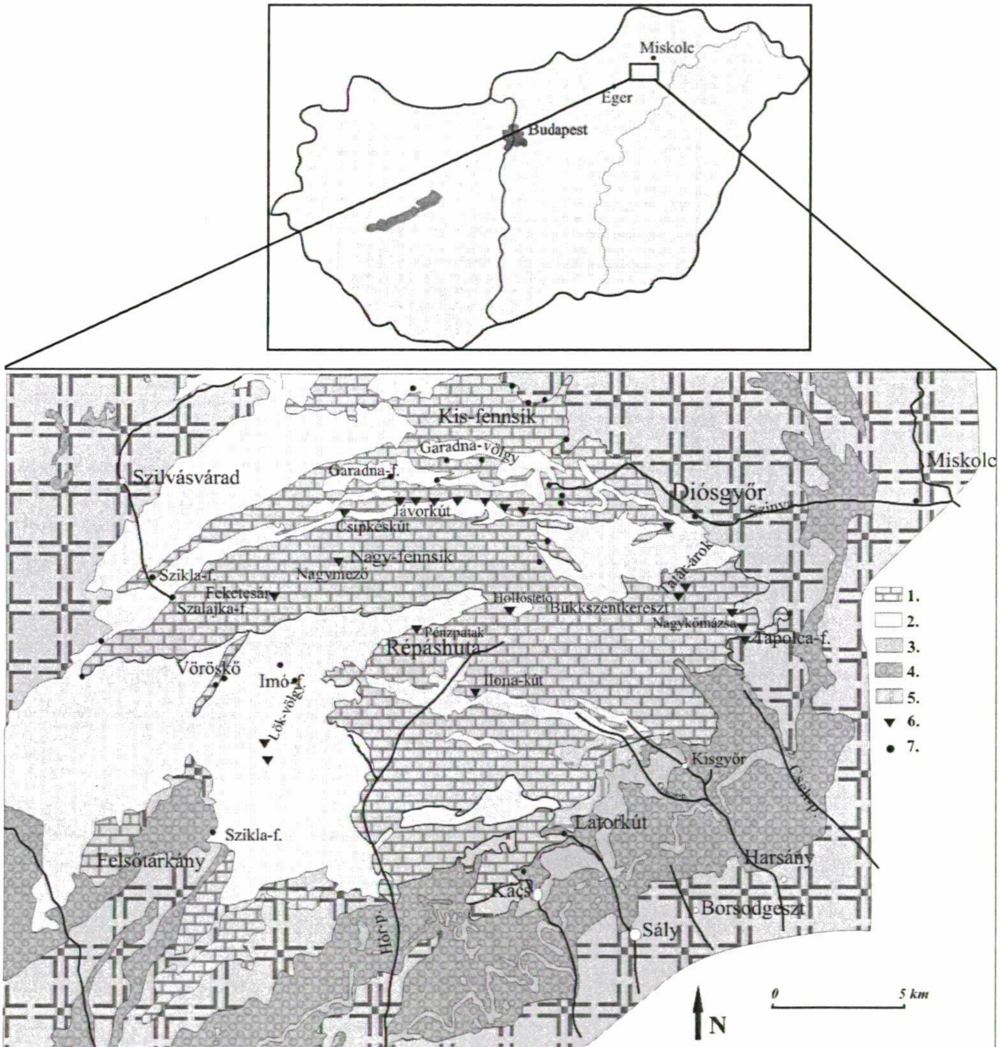

Fig. 1 Geological map of Bükk Mountain, 1. Carbonate rocks, 2. Paleozoic, Mezozoic impermeable rocks, 3 Eruptiv rocks, 4. Rhyolit tuffs, 5. Holocene sediments, 6, Swallow holes, 7. Sources (after Almássy and Scheuer (1967))

The sampling points are the following:

- Kács1: also called Máriás-spring, it is situated in the center of Kács village. The electrical conductivity is the highest in this spring.
- Kács5: The main karst spring of the system, and its water is lukewarm, with little variation of the temperature, which is 14,5°C. It is found above the Kács village.
- Kács6 and Kács7: springs with a temperature of 20-21°C, they are sitauted next to Kács5
- Kács8: also called Tükör-spring. Its water also has a temperature of 21°C, and it can be found beside Kács6 and Kács7.
- Sály1: it is the other main source of the system Kács and Sály. Its temperature is higher than Kács5, 15-16°C, and the magnesium ion content is also higher than the other springs. It is situated 5 km north of Sály.

Bársonyos: A really cold spring, with a temperature of 11°C, and not so high conductivity. It is situated in the Middle of the Bükk Mountains, in the vicinity of Lillafüred.

2. METHODOLOGY

2.1. The field and laboratory measurements, the analysed components

The sampling was carried out fortnightly. I measured the temperature, pH and electrical conductivity with a WTW Cond 40i device. I also measured the components of the carbonate system such as total hardness, calcium, magnesium and HCO_3^- ions. Then I analysed the samples in laboratory by spectrophotometer regarding the phosphate, sulphate, potassium, sodium and chloride content. I followed the methodology suggested by Krawczyk (1996) and Hoffmann and Pellegrin (1997).

2.2. Statistical methodology

The first step during the statistical analysis was to calculate the mean, the minimum and maximum, the standard deviation and the median of the different chemical components for each data series of each sampling points. Although the above statistics give us important information about the different springs, they do not give information about the relationship between the sampling points.

I also calculated the correlation coefficients, and the results are shown in Table 1. It can be seen that conductivity correlates strongly with the sodium, potassium and sulphate ions, and it has correlation with the HCO_3^-ion, but there is no significant correlation with the temperature. Although some ions are more soluble if the temperature is increasing, such as the magnesium ion (it is well known that its solubility is growing with the temperature). The sodium and potassium ions correlate with each other, with the electrical conductivity, but also with the bicarbonate ions.

The correlation coefficient gives us information about the relationships between the different chemical components in a sample, but does not inform us about the relationship between the different samples that are spatially separated. Modern geomathematics advise us to use cluster analysis for such cases.

The aim of the analysis was to find out if the thermal karst wells have some influence on the system of Kács and Sály. I took into account every chemical component with the same weighting factor. The result of the analysis can be plotted in a dendrogram, where we can see the relationships clearly.

Table 1 Correlation matrix for each chemical components

Correlations	T°C	pH	$C\mu Scm^{-1}$	Total Hardness	Mg	HCO_3	Na	K	SO_4
T°C	1.000	-0.140	-0.372	-0.426	0.110**	-0.231	-0.268	-0.219	-0.302
pH	-0.140	1.000	0.240**	-0.024	-0.022	0.002	0.099**	0.279**	0.084*
CμScm-1	-0.372	0.240**	1.000**	0.277**	0.002**	0.098**	0.415**	0.517**	0.511**
Total Hardness	-0.426	-0.024	0.277**	1.000	0.098**	0.678**	0.225**	0.190**	0.211**
Mg	0.110**	-0.022	0.002**	0.098**	1.000	0.184**	0.165**	0.161**	-0.033
HCO3	-0.231	0.002	0.098**	0.678**	0.184**	1.000	0.192**	0.177**	-0.007
Na	-0.268	0.099**	0.415**	0.225**	0.165**	0.192**	1.000	0.308**	0.371**
K	-0.219	0.279**	0.517**	0.190**	0.161**	0.177**	0.308**	1.000	0.298**
SO4	-0.302	0.084*	0.511**	0.211**	-0.033	-0.007	0.371**	0.298**	1.000

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Clustering can be interpreted as a coding process, which features a lot of complex objects described by a number, and the number of its group (cluster number). This code reflects the general and common features of the objects related to one group, so this means the objects in the same group are similar. Of the available methods I applied hierarchical classification. Initially this method considers every element as being in a different group, then merges the classes step by step until every element is in a single class. I chose the Ward clustering methodology for the hierarchical classification. It is based on the information loss resulting of merging the observations in groups. This information loss is the sum of the squared deviation from the group average.

The monitoring of the results was carried out using discriminant analysis. I had to validate the existence of the groups defined by the cluster analysis. The discriminant analysis shows for which variables are the groups created different, namely if class membership can be predicted or not with a selected group of independent variables (Kovács 2010). I used the Wilks' λ statistic for the discriminant analysis. The phenomena in the groundwater is influenced by some parameters more, others less. Wilks' λ gives us the measure of this influence. Its value is between 0 and 1, if it is 1, this means that the examined parameter does not influence the process, but if it is 0, or approximates 0, it has great influence on the groundwater's processes.

2.3. Results

The water of all analysed springs is of a calcium-bicarbonate nature chemically. I found relevant differences in one spring, named Kács1 during the analysis. I measured higher electrical conductivity during the test period, and also higher values of sulphate and phosphate concentrations. The average chemical composition of the analysed sources is shown on the Fig. 2. The dissolved mineral content of the Kács1 sample is higher than the other springs. But its temperature is lower than the other spring's temperature. This discrepancy is partly due to the location of the spring. Kács1 is found in the middle of the settlement, where there is no sewage system at all. The effect of this load was seen almost in each sample, because the phosphate and nitrate contents were always higher than the threshold limit. The other reason is its catchment area. It is built not only of limestone, but a great part of it is rhyolite tuff, which enriches the water with many soluble ions.

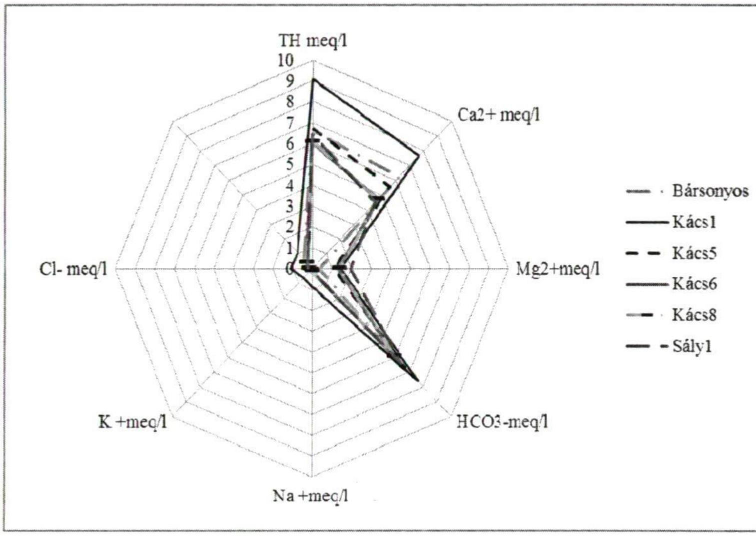

Fig. 2 The chemical composition of the different springs

The above figure shows very well that the chemical parameters of the different springs are similar. The difference is mostly in the quantity of the ion content and not in the quality. According to this fact I thought that after the clustering there would be 3 groups of the different springs. My hypothesis was that the lukewarm springs (Kács5 and Sály) would be in one group, then the warmer springs in another group (such Tükör-forrás, Kács6 and Kács 7), while the third would be formed by the cold water springs (Kács1 and Bársonyos).

However the cluster analysis gave a different result. The finally received cluster centres are shown in the Table 2. As it can be seen, only two groups were formed. The cluster centres show a cold water group and a lukewarm group. In the first group all the tested chemical components have lower value than in the other group. The difference is well marked regarding the potassium, sodium and bicarbonate ions.

Table 2 Final cluster centers

Final Cluster Centers	Cluster	
	1	2
T°C	15.31	11.84
C μScm^{-1}	101.32	153.19
pH	7.32	7.27
SO_4^{2-}mg/l	21.98	48.41
PO_4^{2-}mg/l	0.42	1.22
HCO_3^- mg/l	373.13	463.84
Na^+ mg/l	3.90	19.97
K^+mg/l	3.23	23.24
TH mg/l	318.33	455.10
Mg^{2+} mg/l	15.99	17.78

The dendrogram shows (Fig. 3) that the sampled springs can be classified in 2 groups. The sample Kács1 is one group and the other samples are all in the other group, the Bársonyos spring with cold water, the lukewarm water Kács5, Sály1 and the warm Tükör spring (Kács8). The discriminant analysis showed the same result, so the classification was correct. So in the first group we find the real karst waters, till in the second group the other one.

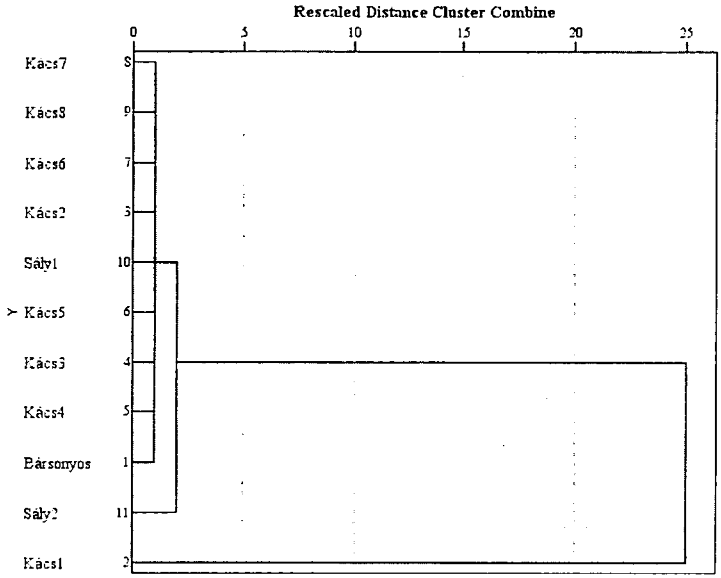

Fig. 3 Dendogram using Ward linkage

The chemical components and variables that the classification was based on are all inorganic ions. Since the correlation coefficient shows the pH has no strong relationship with the other components, that's why I left it out as a classification variable. It seems that the most important classification variables are as follows: the electrical conductivity, the temperature, and the sulphate and phosphate-ion contents. Based on this fact the chemical composition of sample Kács1 is significantly different from the sources and sample points. Therefore in order to ascertain whether there is a real similarity between warm, cold, and lukewarm karst water sources, a study was performed where the data of the spring Kács1 was not taken account. The result is shown on the Fig. 4.

The picture has become more refined and formed the three groups I originally anticipated. So the springs Kács5 and Sály1 really belong together, but they are far from the warm sources as Kács6, Kács7 and Kács8 is, although the sample points are only about some 10 m far away from each other.

Then I wondered if the data of only one sample from the sources and thermal wells from neighbouring catchment area can be placed among the classes, and whether there is any connection with the sources. I carried out the cluster analyses for two time series. If the data of the Kács1 samples were included, I received the same two groups; Miskolctapolca was similar, and could be included in the group with Kács5, Sály1 and Bársonyos springs. But when I tested only the so-called "real" karst springs in themselves, Bársonyos spring and Miskolctapolca are in separate groups (Fig. 5). So it seems that in the period 2004-2006 there was no detectable relationship between the karst springs Kács and Sály and

Miskolctapolca. However the summer of 2006 was not a typical year. There was a heavy rainfall period in the Bükk Mountain, and due to an inundation some karst wells ceased their functioning. It was observed that in this period the discharge of Kács spring increased.

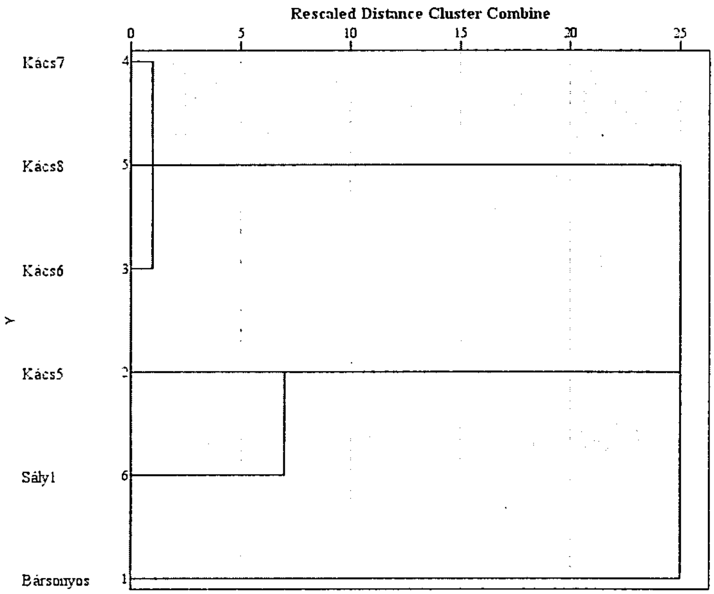

Fig. 4 Result of cluster analysis without sample Kács1

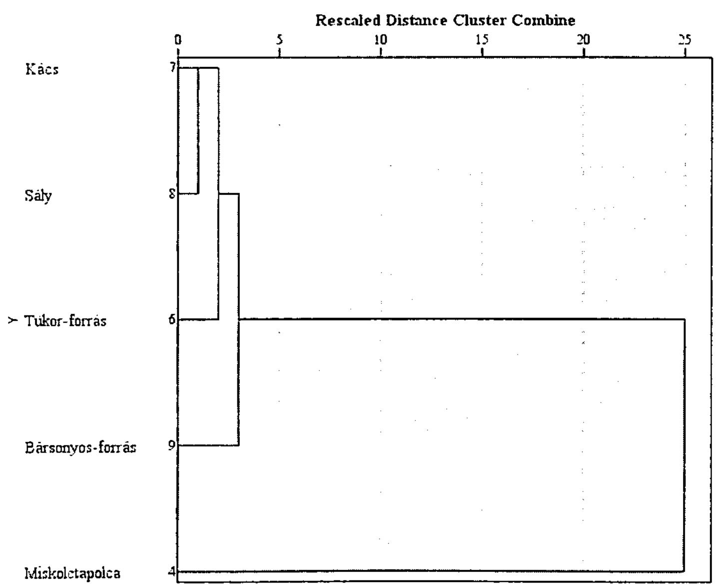

Fig. 5 Result of cluster analysis regarding the sample Miskolctapolca

3. CONCLUSIONS

The field sampling and the laboratory analysis results produced that we could classify the parameters important from the hydrological point of view. Hydrochemical techniques provide significant information about the functioning of karstic aquifer systems and they complement hydrodynamical methods. Chemical compounds can be considered natural tracers that provide information about the structure and dynamics of karst aquifers.

The aim of this study was to detect the possible relationships between the springs using statistical methods. Although regarding the basic chemical composition the sources are close to each other, they form distinct groups. On the whole it can be said that the cluster analysis is an appropriate method to classify karst springs with short or long term data series. Especially if besides the discharge or water level data, time series of chemical components are available.

Since the karst sources of Mountain Bükk are very important drinking water reservoirs for the part of Northern-Hungary, it is important to clarify the possible relationships. The aquifers located in Bükk Mts. have very uncertain borders.

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